chapter 6

# Technology

***"Just as in the 19th Century, when catalogs opened up retail markets and the railroads [transportation] made it happen, in the 21st Century, e-commerce will expand markets and again transportation will make it happen."***

Ted Prince
Journal of Commerce
2025 Visioning Session, Atlanta, GA

***"Technology will not reduce the need for travel, but change its nature and purpose and allow us to meet higher customer demands."***

William W. Millar, President
American Public Transportation Association
2025 Visioning Session, Saint Louis, Missouri, June 13, 2000

***"The PNGV showed us that partnerships work. We need to have more public-private partnerships on fuels, vehicle design, road design, mobility, transit, and intermodalism."***

Curt Magleby
Ford Motor Co.
2025 Visioning Session, Mar. 29, 2000

# chapter 6

# Technology

Dramatic developments in advanced technologies have been the single greatest factor influencing changes in transportation during the past 25 years. In 1975, most of America's transportation infrastructure rested on technologies that were, in some cases, almost a century old. Since then, technology has quietly and thoroughly transformed the nation's transportation systems. We have harnessed the awesome power of technology to improve the safety, capacity, and efficiency of our transportation system. While vehicles and their guideways might appear relatively unchanged, internal changes are occurring rapidly. For example, in personal vehicles, microchips regulate engines; new technologies control the braking systems; and electronic tuning ensures cleaner engine burn. Additionally, vehicle components, materials, and systems are safer than they were 10 years ago. Flame-retardant materials have replaced flammable padding in cars, buses, trains, and airplanes; and a new generation of reinforced plastics has replaced conventional structural materials. Communication, information, and Global Positioning System (GPS)-based navigation are enabling efficient and safer travel. In aviation, aircrafts continue to become quieter, more efficient, and environmentally friendly; and tracking systems have revolutionized the freight industry.

> **Of the top 20 engineering breakthroughs of the 20th century, five were transportation related: the automobile, No. 2; the airplane, No. 3; the Interstate highway system, No. 11; space exploration, No. 12; and petroleum and gas technologies, No. 17 (electrification was No. 1).**
>
> National Academy of Engineering
> National Engineers' Week 2000
> February 2000

As infrastructure nears capacity, particularly in our urban areas, technology is helping to support continuing and growing demands. Advances in technologies for all modes—highways, transit, rail, air, maritime, and pipelines—promise to make our transportation system safer, more efficient, and environmentally friendly. Some of these technologies are described below.

- New information and communications systems have already transformed planning, design, development, maintenance, management, and control of our nation's transportation system. On our highways, video-monitored intersections and synchronized traffic lights are improving safety, capacity, and efficiency of urban and corridor travel. Positive Train Control systems have a similar potential to reduce collisions and improve efficiency by using the satellite-based GPS to monitor rail traffic. Travelers with computer terminals can conduct instant travel planning, reservations, ticketing, and rerouting through Internet connections for many kinds of trips and travel. Electronic tagging technology is used for diverse applications, such as automated toll collection on turnpikes and the automatic identification of freight train contents.

- Advanced material and structural technologies have led to new, environmentally safe, and corrosion-resistant materials with high structural strength (e.g., geosynthetics and fiber-reinforced composites) used in building safer vehicles. Other physical infrastructure improvements include durable recycled pavements and composite wrapping materials to reinforce older structures. New kinds of superconducting and magnetic materials may make high-speed ground transportation more attractive, and improved high-temperature alloys could lead to the development of hypersonic and orbital craft. The emergence of the field of nanotechnology (the building of devices and materials at the level of atoms and molecules) opens a new world of possible technology applications and lighter and stronger materials. For example, nanotechnology could allow for self-healing pavements, which would prevent cracks and other road damage.

- Energy, propulsion, and environmental engineering advances provide options to deliver improved transportation service that is less costly, more energy-efficient, and environmentally safe. A variety of new power plants for personal vehicles have entered operation on a test basis; hybrids that use gasoline-electric engines, and vehicles with alternative-fueled engines will have particularly broad impacts. The use of alternative fuels, such as natural gas, can reduce emissions of nitrogen oxides, energy costs, power plant maintenance costs, and dependence on foreign oil. Turbine-powered locomotives, now under development, are expected to accelerate implementation of high-speed rail corridor services throughout the country. New technology turbojet/turbofan, ramjet and scramjet (supersonic combustion ramjet), and linear aerospike engines could transform aviation during the next quarter century.

- Advanced simulation systems enable better evaluation of technological alternatives and allow more informed transportation investment decisionmaking.

- Improvements in information technology will facilitate timelines and improved data collection and dissemination.

Today's $300 billion telecommunications industry is becoming inextricably linked with the transportation system. Transportation moves people and products, while communications move data and ideas. The two systems provide a link and network for billions of users across the globe and reinforce each other's growth. GPS-aided in-car navigation and other satellite-based services serving multimodal transportation users become possible with real-time communication links to satellites. Geographic information systems will use real-time data from GPS to become a major resource for planners of future transportation systems.

The following sections provide a detailed description of past and future technological advances in GPS; Intelligent Transportation Systems (ITS); high-speed ground transportation; and railroad, aviation, and maritime system technologies.

# Global Positioning Systems

GPS is a fully operational, worldwide, all-weather, satellite-based navigation system originally developed in the 1970s. The system has three parts: *the space segment*, *the user segment*, and *the control segment*. The space segment consists of 24 satellites, each in its own orbit, 11,000 nautical miles above the Earth; the user segment consists of receivers, which can be handheld or mounted in a car; and the control segment consists of ground stations (five, located around the world) that ensure the satellites are working properly [The Aerospace Corp. 1997]. GPS receivers receive these signals, measure the relative arrival times, and from these, compute the user's position. Using signals from at least four satellites, a GPS receiver can determine three-dimensional geographic coordinates. The United States provides free GPS service worldwide.

GPS began with the first satellite launch in 1978 and was completed by 1994 with the deployment of the 24th satellite, creating a virtual net of satellite coverage over the entire globe [The Aerospace Corp. 1997]. The Department of Defense (DOD) originally created GPS to provide

U.S. and Allied forces with accurate positioning information throughout the globe [Trimble 2000]. Allied forces successfully used GPS during Operation Desert Storm to carry out complex military maneuvers on land, sea, and in the air [The Aerospace Corp. 1997].

The commercial benefits of GPS became apparent in the early 1990s. Ground-based radio-navigation systems were limited in their use; high-frequency radio waves could provide accurate positioning but within a limited area; and lower frequency radio waves (AM radio) provided coverage over larger areas but provided inaccurate positioning. With increased global trade and development of complex logistics, the need for accurate global positioning became more apparent [The Aerospace Corp. 1997]. The GPS solved this problem by providing accurate worldwide satellite coverage, and today, the use of GPS in the civil/commercial sector has grown as the accuracy of positioning information has increased.

Until recently, for national security reasons, the DOD deliberately introduced error into the GPS signal for civilian and commercial uses. This practice, termed Selective Availability (SA), provided accuracy of GPS signals to only within 300 feet for civilian and commercial use [USDOC 2000].

In an effort to increase the reliability and accuracy of GPS and to encourage its peaceful civilian use, President Clinton issued a Presidential Decision Directive in March 1996, committing the United States to discontinue the use of SA by 2006. But, on recommendation by the Secretary of Defense, in coordination with the Departments of State, Transportation, and Commerce, the Director of Central Intelligence, and other Executive Branch departments and agencies, President Clinton announced the immediate discontinuation of SA on May 1st 2000, increasing the positioning accuracy of GPS to within 60 feet for civilian and commercial usage [USDOC 2000].

***"The same technology that helped our troops succeed in Desert Storm will bring us safer air travel throughout the world, improved transportation on our roads and highways, and faster response to emergencies by rescue vehicles. And it will help America's industries lead the world."***

**President William J. Clinton**
President Opens Door to Commercial GPS Markets; Move Could Add 100,000 New Jobs to Economy by Year 2000 (press release)
Mar. 29, 1996

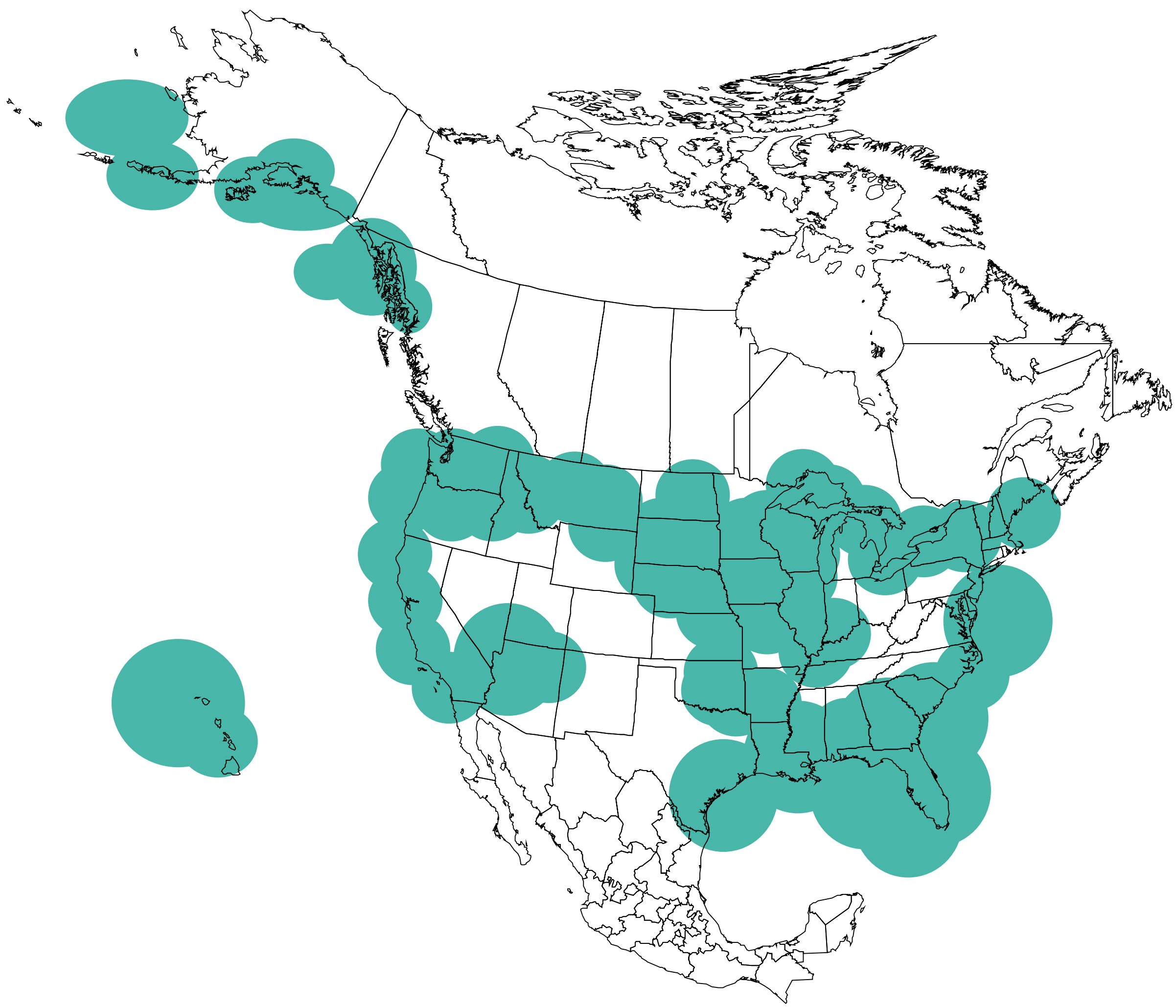
**Differential GPS:** To provide more reliable and accurate satellite navigation for civilian transportation, the U.S. Department of Transportation (USDOT) is implementing GPS "augmentations" based on a technique known as "Differential" GPS (DGPS). DGPS provides civilian and commercial users predictable accuracy of better than 10 meters (2 drms) in the coverage area and typically better than 1 meter within 150 km of the reference station [USDOC 2000] (figure 6-1).

A DGPS ground-based reference station continuously monitors GPS signals; and because the position of the reference station is precisely known, errors in satellite signals can be calculated and corrections broadcast to area users. The users' DGPS receivers apply the correction message to improve the accuracy of its own position. The DGPS broadcast may also include warnings to inform users when the system is unreliable for navigation. While it is highly accurate, DGPS relies on ground stations, which limits its geographic coverage over large expanses of water. However, this limitation has not prevented development of a variety of DGPS–based technologies for various transportation applications. Maritime DGPS sites incorporate NOAA's GPS Surface Observing Systems (GSOS) for measuring weather data and precipital water vapor measurements for forecasting. In addition, all sites have integrated NOAA's Continuously Operated Reference Station (CORS) equipment used for precise positioning and survey uses.

Automatic Vehicle Location (AVL) is a technology used for tracking vehicles; vessels; and mobile assets such as trailers, containers, and equipment. Each mobile unit has a GPS receiver that reports its position to the base station over a communications network, allowing

Figure 6-1

**Nationwide Differential GPS Coverage as of November 2000**



Source: U.S. Department of Transportation, Coast Guard Navigation Center, personal communication, October 2000.

the base station to monitor the entire fleet and manage mobile assets. This permits more reliable and timely logistics, more precise in-car satellite navigation, and more effective emergency responses (see also section on Intelligent Transportation Systems).

Satellite navigation also provides unprecedented accuracy and capabilities for mariners and maritime transportation managers. Underwater surveying, buoy placement, navigational hazard location, and mapping are increasingly being executed using satellite navigation signal data. Commercial fishing fleets use satellite navigation to locate optimum fishing locations and to track fish migrations. Quick access to accurate position, course, and speed information will save time and fuel by providing more efficient traffic routing.

Many railroad systems are comprised of long stretches of single track. Precise knowledge of a train's location is essential to prevent collisions, maintain smooth traffic flow, and minimize costly delays waiting for a track to clear. Satellite navigation provides a sound position-locating capability for rail traffic management systems, be it to manage the movement of cars and engines in switchyards or to ensure worker safety. Current technology also allows for fully automated train control through the use of DGPS capability, digital maps, and onboard inertial units.

Important applications of the GPS in aviation are under development and may be deployed in the near future. These are discussed under Keys to the Future. While we have described transportation-related uses of GPS above, there are many other civilian uses of GPS. GPS is being applied in the field of mapping and land surveys; construction of tunnels; location and dispatch of police, fire, and emergency medical services; wildlife management; and the use of GPS-equipped balloons to monitor air quality and holes in the ozone layer over polar regions.

## Keys to the Future

The USDOT is carrying out three types of DGPS augmentations to meet the requirements of transportation—maritime, land, and aviation.

The *Nationwide Differential Global Positioning System (NDGPS)* is being implemented for surface transportation (maritime and land). Current coverage consists primarily of the USCG's Maritime DGPS Service, which is fully operational. More than 30 foreign countries also recognize the value of DGPS and have implemented surface DGPS services that conform to the USCG standard [USDOC 2000].

The Federal Aviation Administration (FAA) is implementing GPS augmentation systems for aviation. Together, the *Wide Area Augmentation System (WAAS)* and the *Local Area Augmentation System (LAAS)* will support all phases of flight. The Chicago metropolitan area's O'Hare International and Midway airports will be the initial testbeds for the LAAS. WAAS will provide guidance for en route flight, terminal, and approach operations. It sends differential correction and message reliability to aircraft via geostationary earth-orbit (GEO) satellites at the same frequency as the GPS, thus providing greater accuracy. LAAS will provide greater accuracy in all weather conditions for the more stringent approach and surface operations. The LAAS is intended to complement the WAAS; together they supply users with seamless, satellite-based navigation for all phases of flight and permit the full development of Free Flight (box 6-1) [USDOT 2000].

The USDOT, along with other federal government departments and agencies, including the DOD, is seeking to improve GPS services through a modernization program. Future GPS satellites will have three civilian signals: two frequencies will be protected for radio navigation, including aviation, and the third for nonaviation civilian uses. There also will be new military signals [USDOT 2000].

Box 6-1

**Free Flight**

Pilots today pick from a very limited set of routes and altitudes. But, with GPS navigation, a pilot is allowed Free Flight—the ability to select the safest and most fuel-efficient route. Through continuous tracking of a plane's position in relation to that of other planes, a Free Flight path can be changed manually or by computer to avoid extreme weather conditions or the possibility of collision with terrain or other aircraft. Tests have been conducted in the United States and over the central Pacific, and the results have been encouraging. Free Flight should be used by a significant portion of the world's airlines by 2010. Benefits of Free Flight include shorter flight times, cost savings, safer flights, lower energy use, and less pollution.

Sources: Trimble Navigation Limited, *All About GPS*, available at http://www.trimble.com/gps/index.htm, as of Aug. 18, 2000; U.S. Department of Transportation, Federal Aviation Administration, *Free Flight*, available at http://www.faa.gov/freeflight/ff-OV.htm, as of Aug. 10, 2000.

Box 6-2

**Galileo—The European 'Satellite Navigation Initiative'**

Galileo is an initiative of the European Union, in collaboration with the European Space Agency and the private sector, to provide a European civilian-controlled satellite navigation system. As of today, it is still in the planning stage with system design and development to be initiated on January 1, 2001, and deployment to be completed by the end of 2008. Galileo provides a European alternative to GPS and will seek to achieve interoperability with GPS for the benefit of the user community.

Galileo will operate on three levels. The global component will provide basic positioning services of the Galileo system worldwide. A regional component will fulfill a higher performance requirement on a regional basis especially on a European geographic level. The local component aims to increase the accuracy and integrity of the service over local areas, such as airports or harbors. The primary means for this is a local differential station, located in a fixed and well-known position, which can then calculate the local errors in the Galileo signals and broadcast the associated corrections to the users.

Source: Galileo Definition Phase Initial Results, available at www.galileo-pgm.org as of October 5, 2000.

This modernization should provide civilian and commercial users with both the accuracy of DGPS and worldwide coverage. The availability of multiple signals will make the modernized GPS more resistant to atmospheric interference. By 2015, civilian use of GPS is projected to achieve a positioning accuracy to within 15 feet, anywhere in the world [USDOT 2000].

## Intelligent Transportation Systems

ITS represents the application of advanced technologies involving information processing, electronics and communication, and management strategies to improve our transportation system. Benefits associated with ITS include improved safety, increased system capacity, reduced travel times, and improved productivity. In short, ITS is using technology to make travel smarter.

ITS technologies can be divided into four functional areas—Metropolitan ITS, Rural ITS, Intelligent Vehicle Initiative (IVI), and Commercial Vehicles Operations (CVO). Each of these functional areas has a set of interlinked systems, which are discussed in this section.

***"I want 75 of our largest metropolitan areas with a complete Intelligent Transportation Infrastructure in 10 years. And let us make a similar commitment to upgrading technology in 450 other communities, our rural roads, and Interstates, as the need warrants."***

**Federico Peña**
Former Secretary of Transportation
Transportation Research Board
Jan. 10, 1996

The roots of ITS predate the establishment of a formal program by several decades. The world's first centralized traffic signal control system was installed in Toronto, Canada, in 1963. The first metered ramp was installed in Chicago on the Eisenhower Expressway in 1963. The Federal Highway Administration (FHWA) conducted research on an Electronic Route Guidance System (ERGS) in the late 1960s. These early efforts, however, were isolated and costly; although some, such as ERGS, were ahead of the times.

ITS in its current form emerged only in the late 1980s. Its growth and development were encouraged by several factors:

- The revolution in electronics and information technology generated dramatic performance/cost improvements in computer, sensor, and communications technologies.
- Concerns over traffic congestion, traffic safety, and air quality were growing.
- There was an increasing realization that new construction alone would not solve these problems.
- There was growing concern that European and Japanese ITS initiatives would reduce the competitiveness of the U.S. transportation industry.

Charlie Westerman/Chicago

In-vehicle navigation devices (most commonly found in rental and luxury cars) provide drivers with navigational assistance while en route to their destination

The most significant incentives in ITS development came from three sources: an ad hoc public-private-academic partnership called Mobility 2000, an independent study by the National Academy of Sciences, and a congressionally requested USDOT study. The recommendations of these groups resulted in the passage of the Intelligent Vehicle Highway System (IVHS) Act in 1991. The act called for a "national system of travel support technology, smoothly coordinated among modes and jurisdictions to promote safe, expeditious, and economical movement of goods and people." The federal focus was placed on research, development, and operational testing of ITS technologies and standards (box 6-3).

The Transportation Efficiency Act for the 21st Century (TEA-21), which President Clinton signed into law in 1998, recognized the maturity of many ITS-related technologies and broadened federal focus to place an equal importance on deployment. Similarly, state and local governments, as well as private industry, had begun deploying ITS.

**Box 6-3**

**Standards Development**

The USDOT-led creation of a national ITS architecture and the drafting of related standards are intended to lead to the development of open, interchangeable systems and components. This common architecture serves as a framework for regional ITS planning throughout the United States, and it has become a model for similar architecture development efforts now underway in Canada, the European Union, and Japan.

The growth in deployment is demonstrated through federal spending on ITS infrastructure, which totaled $1.3 billion from FY 1991 to FY 1997 [USGAO 1997]. These funds were primarily invested in Freeway Management Systems and Coordinated Traffic Signal Control Systems. ITS is being deployed across the country, and the rate of both public- and private-sector deployments appears to be increasing. Figure 6-2 shows the actual federal funding for ITS infrastructure from 1997 to 1999 and targeted funding through 2003 under TEA-21.

Between 1991 and 1999, ITS technologies, such as electronic toll collection and freeway monitoring systems, were increasingly deployed throughout the country. Figure 6-3 illustrates the deployment of ITS technologies among the 78 largest metropolitan areas with ITS deployments. Early testing, such as the TravTek test in Orlando, Florida, during 1991 and 1992, and ADVANCE in Chicago, Illinois, led to niche deployment of in-vehicle navigation systems. During this same period, the Internet became a global phenomenon, and civilian use of the GPS became available and affordable.

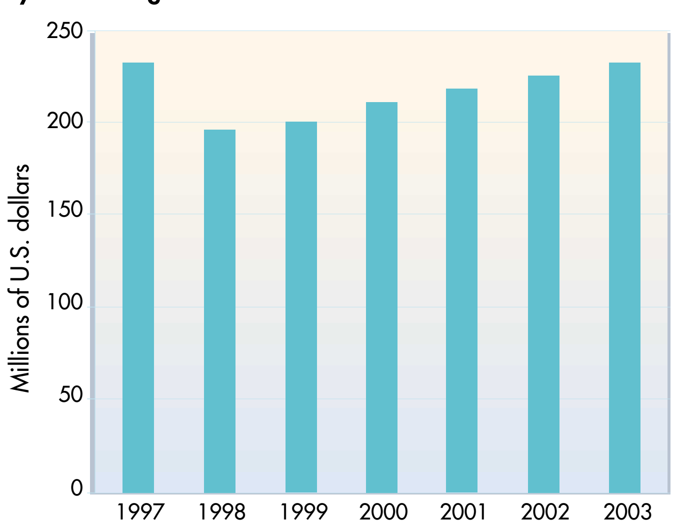
The following subsections discuss the first 10 years of ITS research, testing, and deployment, from 1991 through 2000.

**Metropolitan ITS:** Metropolitan ITS infrastructure is made up of nine major components, including Arterial Management Systems, Freeway Management Systems, Transit Management Systems, Incident Management Systems, Emergency Management, Electronic Toll Collection (ETC), Electronic Fare Payment, Highway-Rail Intersections, and Regional Multimodal Traveler Information. Table 6-1 shows these various components of Metropolitan ITS and their benefits.

*Arterial Management Systems* involve the use of roadside devices, communications equipment, and specialized software to improve traffic flow along local roads and arterials (non-freeway roadways). Primary focus is on traffic signal control to alleviate congestion; secondary emphasis is on signal pre-emption or prioritization for emergency and transit vehicles and intersection monitoring. The signal pre-emption technology, where a traffic signal turns to green as a transit bus approaches the intersection, can reduce travel times by up to 30 percent [Hagler Bailly 1999]. Figure 6-4 shows the number of metropolitan areas where different types of traffic signal control technologies are deployed.

**Figure 6-2**

**Federal Funding for Intelligent Transportation Systems Program: 1997-2003**

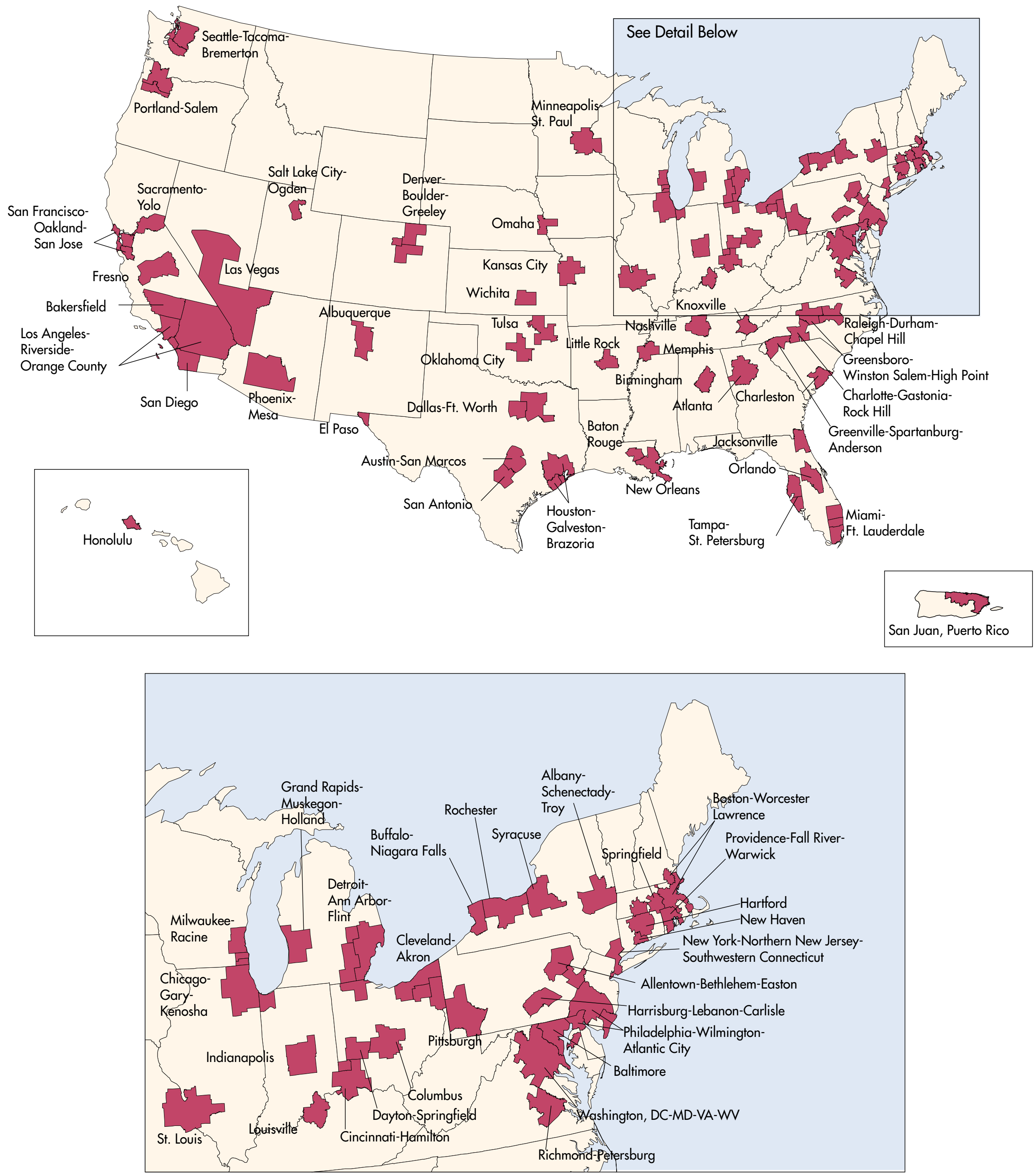



Note: 1997 data reflect funding from multiple sources. 1998 to 2003 data include ITS Research and Development funds and ITS Deployment funds.

Source: U.S. Department of Transportation, Federal Highway Administration, *TEA-21 Fact Sheet – Intelligent Transportation Systems Program* (Washington, DC: 1998).

Figure 6-3

## The Largest 78 Metropolitan Areas with ITS Deployments: 1997




Source: U.S. Department of Transportation, Federal Highway Administration, Joint Program Office for Intelligent Transportation Systems, *Tracking the Deployment of the Integrated Metropolitan Intelligent Transportation Systems Infrastructure in the USA: FY 1997 Results* (Washington, DC: 1999).

Table 6-1

**Metropolitan Intelligent Transportation System Infrastructure—Functions and Benefits**

| Infrastructure | Functions | Benefits Provided |
|---|---|---|
| Arterial management | Monitor arterial network traffic<br>Implement range of adaptive control strategies<br>Manage area-wide signal coordination | Safety, decreased travel times, increased capacity, fuel savings/lower emissions, customer satisfaction |
| Freeway management | Monitor freeway conditions<br>Identify flow impediments<br>Control ramp metering and lane control<br>Control highway advisory radios | Safety, decreased travel times, increased capacity |
| Incident management | Incident detection<br>Incident response/clearance | Safety, decreased travel times, fuel savings/lower emissions |
| Transit management | Monitor transit vehicle position<br>Disseminate real-time schedules<br>Provide computer-aided dispatch<br>Provide vehicle condition monitoring | Safety, decreased travel times, lower costs, customer satisfaction |
| Electronic fare payment | Provide payment at station/stop or in-vehicle | Decreased travel times, customer satisfaction |
| Electronic toll collection | Provide payment at toll collection stop | Decreased travel times, increased capacity, lower costs |
| Emergency management | Monitor vehicle location<br>Provide fleet management support | Decreased travel times, customer satisfaction |
| Highway-rail crossing management | Provide remote monitoring of highway-rail intersections | Safety |
| Regional multimodal traveler information | Provide information distribution on weather conditions | Lower costs, customer satisfaction, fuel savings/lower emissions |

Source: A. Proper, *Intelligent Transportation Systems Benefits: 1999 Update*, prepared by Mitretek Systems for the Federal Highway Administration, U.S. Department of Transportation, 1999, available at www.its.gov/eval/itsbenefits.htminventory99b.pdf, as of Aug.18, 2000.

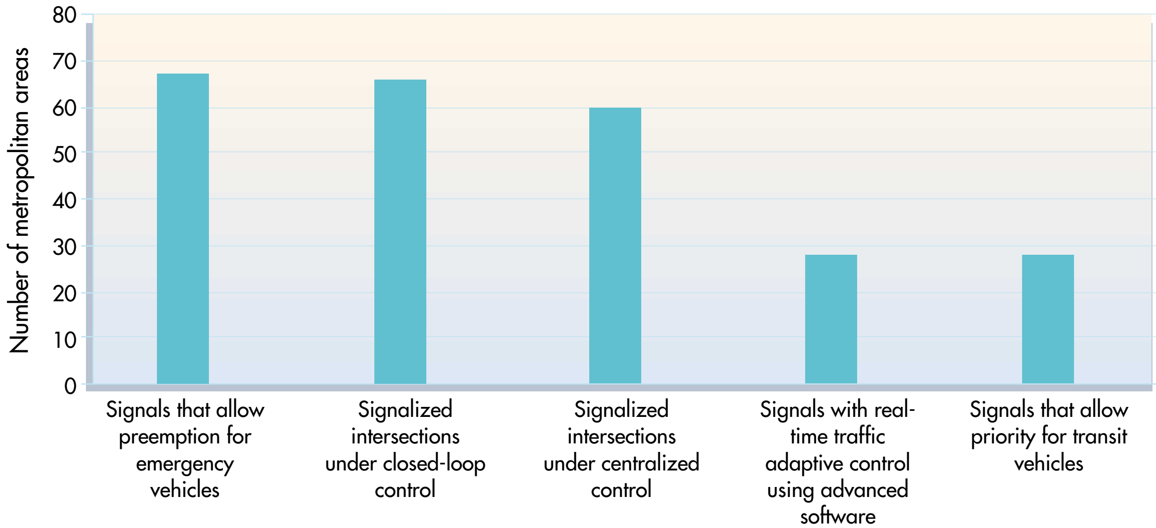
*Freeway and Incident Management Systems* include ramp metering programs, freeway surveillance systems, incident response systems, and information display or communications systems (e.g., variable message signs and highway advisory radio). Ramp meters are traffic signals on freeway entrance ramps that supply traffic to the freeway in a measured or regulated amount. The number of cities with ramp metering has remained fairly constant during the decade (22 of the largest 78 metropolitan areas employ ramp metering) (figure 6-5), but the number of ramps that are metered has increased. Surveillance systems, such as loop detectors and video cameras, became widely deployed on the freeways during the 1990s (figure 6-6). As the decade ended, a few localities also were beginning to provide video surveillance at major intersections to reduce the incidence of red-light running.

The acceptance of automated enforcement technology, while still controversial, has grown as the limited use of automated traffic signal enforcement has shown large benefits. For example, Fairfax City, Virginia, showed a 35 percent reduction in red-light running incidents after installing enforcement systems.

*Transit Management Systems* were deployed in the 1990s by many large and small transit agencies. Typical systems included AVL and Computer-Aided Dispatch (CAD) systems. These systems date back several decades, but in the 1990s, GPS became the primary location technology, due to its general reliability and decreasing cost. These systems delivered improved service reliability, improved operator visibility into problems, and enhanced security. A 1996 study found that 22 transit agencies had equipped 7,000 vehicles with AVL, and another 47 agencies were in the process of securing AVL systems. The passage of the Americans with Disabilities Act (ADA) also guaranteed increased demand for AVL and CAD

**Figure 6-4**

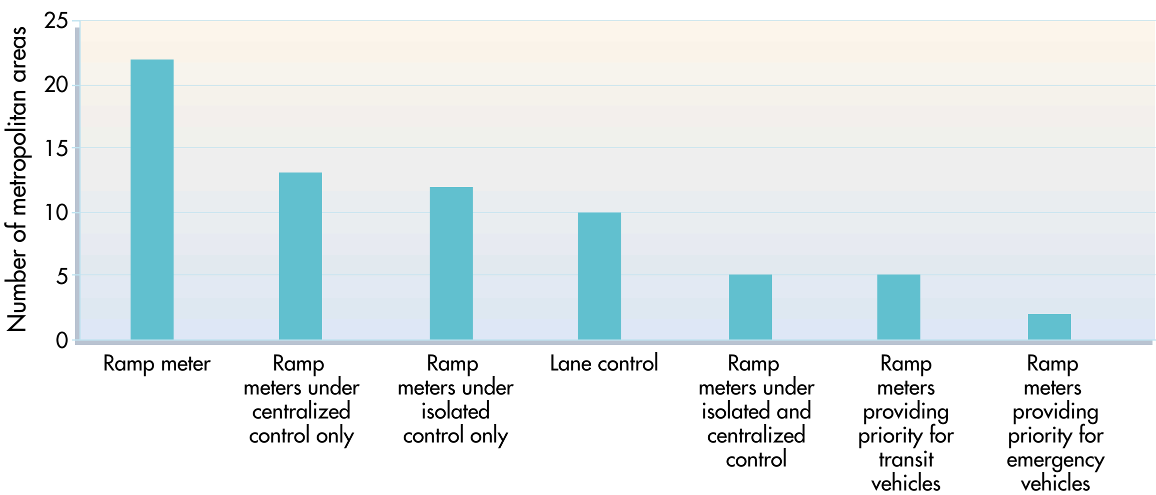
**Deployment of Traffic Signal Control Technologies: 1997**




Source: U.S. Department of Transportation, Federal Highway Administration, Joint Program Office for Intelligent Transportation Systems, *Tracking the Deployment of the Integrated Metropolitan Intelligent Transportation Systems Infrastructure in the USA, FY 1997 Results* (Washington, DC: 1998).

**Figure 6-5**

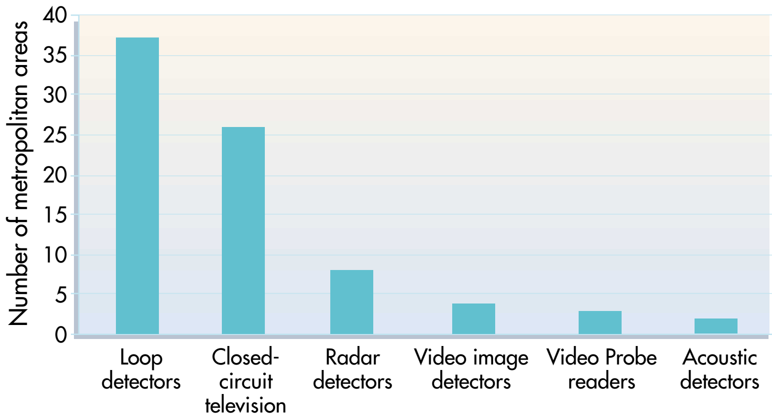
**Deployment of Freeway Management Traffic Control Technologies: 1997**




Source: U.S. Department of Transportation, Federal Highway Administration, Joint Program Office for Intelligent Transportation Systems, *Tracking the Deployment of the Integrated Metropolitan Intelligent Transportation Systems Infrastructure in the USA, FY 1997 Results* (Washington, DC: 1998).

Figure 6-6

Deployment of Freeway Surveillance Systems: 1997




Source: U.S. Department of Transportation, Federal Highway Administration, Joint Program Office for Intelligent Transportation Systems, *Tracking the Deployment of the Integrated Metropolitan Intelligent Transportation Systems Infrastructure in the USA, FY 1997 Results* (Washington, DC: 1998).

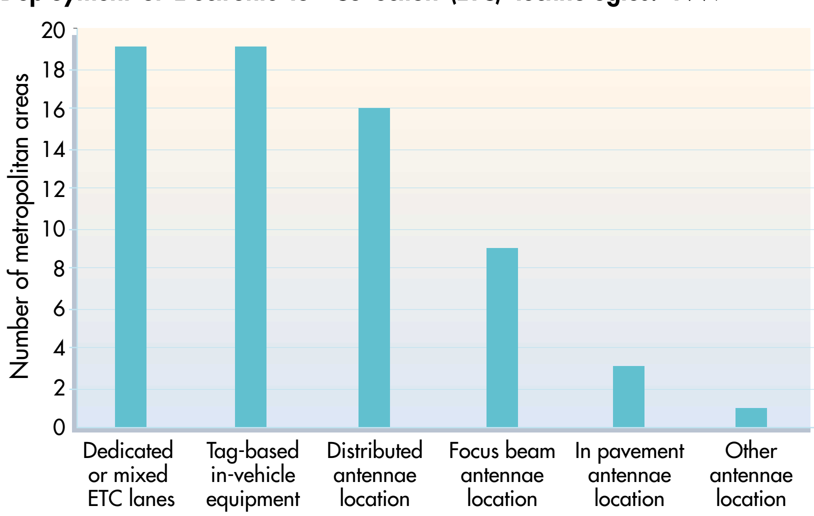
systems, as well as for communications, automatic stop annunciation, and other technologies [McGurrin 2000].

*Electronic Toll Collection* (ETC) deploys various communication and electronic technologies to support the automated collection of payment at toll plazas and other collection points. ETC is among the most successful ITS applications (figure 6-7). Since the first electronic toll system was installed in New Orleans in 1989, more than 100 facilities in 39 areas have installed ETC systems, and the number of vehicles equipped with radio frequency toll tags has grown to more than four million. The Oklahoma turnpike has estimated that the operating cost for an electronic toll lane is less than one-tenth that of a standard lane. The Triborough Bridge and Tunnel Authority found that the increased throughput of ETC lanes has shortened the evening congestion period by 90 minutes on the Verrazano Narrows Bridge [Shibata & French 1996].

*Electronic Fare Payment* systems were tested or deployed by a number of transit agencies during the 1990s. Although only a limited number of systems have been deployed, the rate of deployment is expected to increase because reliable and fast systems are now available. These systems reduce operating costs (due to reduced cash handling), can aid in passenger counting, and are convenient for passengers. This convenience is expected to increase as the

Figure 6-7

Deployment of Electronic Toll Collection (ETC) Technologies: 1997




Source: U.S. Department of Transportation, Federal Highway Administration, Joint Program Office for Intelligent Transportation Systems, *Tracking the Deployment of the Integrated Metropolitan Intelligent Transportation Systems Infrastructure in the USA: FY 1997 Results* (Washington, DC: 1998).

payment systems become integrated with other applications and one card can be used for many purposes.

Georgia Department of Transportation

Advanced Traffic Management Centers (TMCs), such as this one in Atlanta, Georgia, allow traffic engineers and operations personnel to proactively manage the freeway and arterial street systems while providing a comprehensive source of real-time traffic data for traveler information systems.

*Regional Multimodal Traveler Information* is being supplied by several transit agencies that have started using traveler information kiosks and Internet sites to provide schedules, expected arrival times, expected trip times, and route planning services to patrons. Also, several traffic management centers are providing current traffic conditions and expected travel times using similar approaches. These services allow users to make a more informed decision for trip departures, routes, and travel. They have been shown to increase transit usage and may help to reduce congestion when travelers choose to defer or postpone trips or select alternate routes.

Traveler information via the Internet went from nonexistent in 1990 to widespread deployment by 2000. Today, nearly every state provides highway construction and/or road closure information via the Internet (box 6-4). Thirty-five of the 75 largest cities make real-time freeway traffic information available [Gordon 1999].

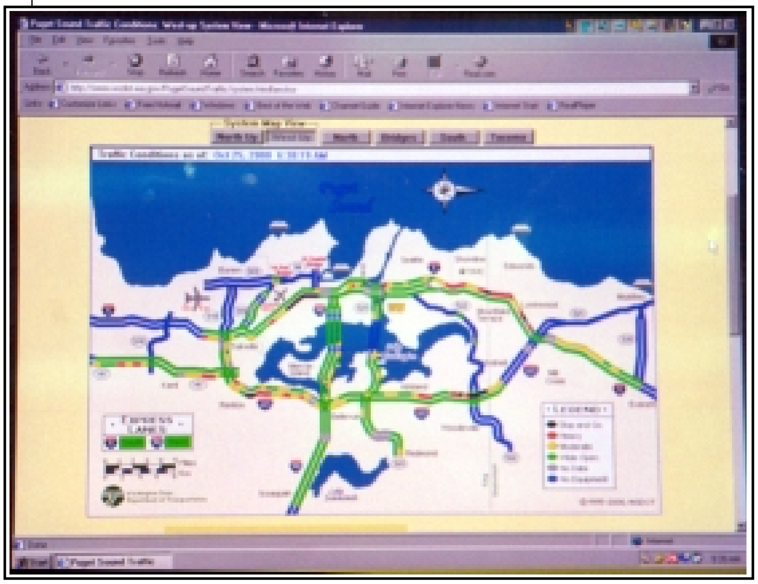
**Box 6-4**

**ITS and the Internet**

The Internet will play an increasingly important role in disseminating traveler information. Currently, the Internet is used primarily for semiautomated information exchange, in which people use a browser to pull information on traffic conditions and transit schedules from an automated server. The next major stage in the evolution of the Internet will be support for fully automated information exchange. This will be supported by the widespread availability of high-speed Internet access; low-cost, adequate security; and new standards. These trends will increase the utility of Internet-based real-time and predictive traffic information, both between agencies and consumers, with benefits also provided to commercial vehicle operations, fleet management, and intermodal freight tracking.

**Rural ITS:** Rural travelers need the same basic ITS services required by urban travelers, but the priorities are different. These priorities and needs reflect the conditions in rural localities: generally longer local travel distances; lower traffic volumes; longer emergency response times; sparse and patchy telecommunications infrastructure; and a dispersed system with high unit costs for service delivery, operations, and maintenance.

As a result, there is an emphasis on *weather and road condition information* for all rural highway users and on the use of *automatic vehicle location* and computer-aided *dispatch systems* for rural transit and paratransit services. Automated collision notification and mayday services are already operational in some areas. Improving traveler information in National Parks also is an important initiative under Rural ITS. Table 6-2 shows the major components of Rural ITS and their benefits.



Washington State Department of Transportation

State and local departments of transportation make use of the Internet to provide real-time traveler information to the public. Dynamic Web pages are linked to advanced traffic management systems to display real-time travel speed, incident and road construction information.

**Intelligent Vehicle Initiative:** Following the successful testing in 1997 at San Diego, California, the federal Automated Highway System program became the Intelligent Vehicle Initiative, with a focus on implementable, near-term safety improvements. Automated highway research, such as the California Department of Transportation-supported research into fully automated vehicle operation, continued at a lower level. Three important sets of technologies under this initiative are discussed below.

*In-Vehicle Navigation and Dynamic Route Guidance (using real-time traffic information)* can provide turn-by-turn instructions to guide travelers to their destinations and support travel-related services (gas stations, hotels, and parking). Within a few years, navigation systems will be able to incorporate data on traffic conditions in real-time and adapt the preferred route accordingly. This system may incorporate the use of GPS antennas and receivers, Liquid Crystal Display (LCD) panels, Compact Disk-Read Only Memory/Digital Video Disk (CD-ROM/DVD) players, communications hardware, driver interface units, map databases, and route optimization programs. These technologies have established a niche in the rental car market and in some higher-end car models, but their use is spreading with the increasing accuracy and falling costs of component technologies [Proper 1999].

**Table 6-2**

**Rural ITS Infrastructure—Functions and Benefits**

| Infrastructure | Functions | Benefits Provided |
|---|---|---|
| Travel safety and security | Hazardous conditions information<br>Surveillance | Safety, customer satisfaction |
| Emergency services | Incident notification mobilization and response | Safety |
| Tourism and travel information | Route selection, navigation, and services information | Customer satisfaction |
| Operation and maintenance | Traffic management | Decreased travel times, lower costs |
| Public travel and mobility services | Transit accessibility<br>Dispatch and routing<br>Ride sharing and matching | Fuel, savings/lower emissions, customer satisfaction |

Source: U.S. Department of Transportation, Federal Highway Administration, Joint Program Office for Intelligent Transportation Systems, *Measuring ITS Deployment and Integration,* Version 2 (Washington, DC: January 1999).

*Collision Avoidance and Warning Systems* are expected to improve highway safety by reducing the number of crashes. Collision avoidance includes several user services, such as Intelligent Cruise Control, Rear-End Crash Avoidance, and Road Departure Avoidance. Each of these is described in detail in Chapter 3 under Highway Safety.

*Mayday and Security Systems* combine wireless communications and positioning information to enhance driver/passenger safety. The Mayday System enables the driver (or vehicle) to notify emergency services immediately in the event of an accident. As an added feature, travelers can contact roadside assistance, request navigation assistance, and track a stolen vehicle. Typical systems consist of in-vehicle hardware and a monthly service charge. Applicable hardware includes GPS antennas and receivers and communications hardware [Hagler Bailly 2000].

**Commercial Vehicle Operations (CVO):** The ITS/CVO initiative is expected to improve administrative efficiency, highway data collection, and safety, and also reduce operating costs of commercial vehicles. Currently, ITS/CVO covers three areas of state motor vehicle regulations. These are discussed below.

*Electronic Screening* can result in reduced congestion at weigh and inspection stations by allowing safe and legal carriers to bypass without stopping. Roadside electronic screening allows authorities to concentrate on greater percentages of potentially unsafe vehicles.

*Safety Information Exchange Programs* will assist in improving the safe operation of commercial vehicles. These programs will provide inspectors with better access to safety information, increasing the number of unsafe commercial drivers and vehicles removed from the highway. On-board monitoring of cargo can alert drivers and carriers of potential unsafe load conditions.

*Credentials Administration* will support in-house administrative functions and can provide savings to state and administrative agencies. Electronic credentialing can improve the time required for states to approve operating permits. Data warehouses can facilitate the exchange of credentials data between agencies and states.

## Keys to the Future

By 2010, high quality, real-time travel information will be generally available for urban and heavily used Interstate routes, usually via wireless receivers. By 2025, real-time transportation management will be a reality, with highways and transit not just monitored, but proactively managed. For example, traffic control strategies will be closely coordinated to prevent alternative routes from becoming congested after a primary route becomes congested.

By 2025, improved sensors, sophisticated algorithms, and more powerful computers will yield systems that greatly improve driver situational awareness, vehicle controllability, and crashworthiness, as well as sense driver incapacitation due to fatigue, alcohol, drugs, or any other cause. Voice recognition for various functions will minimize problems caused by driver inattention resulting from distraction or other factors. Full integration of these systems into vehicle design, coupled with external inputs regarding weather, road conditions, intentions, or status of nearby vehicles, and other safety advisories, will extend the dramatic decline in fatality and injury rates that began in the early 1970s.

Open standards-based traffic management equipment now in development will support interoperability, which will promote new entrants and encourage development of new technologies. Today's cluster of intelligent transportation vehicles and travel planning and information services will be integrated in new vehicles with smart driver-operator technologies, in-car sensors, on-board emission management systems, and links to wayside information infrastructure. Advanced multispectral sensors, distributed microprocessors, communications, tracking technologies, and traffic information displays in urban traffic management centers will improve safety, enable more efficient use of limited infrastructure capacity, relieve congestion, and lessen the environmental impacts of transportation. Travelers will benefit from integrated trip planning, scheduling, and routing options—the result of in-car navigation and information systems that are linked directly into the vehicle's electronics systems to provide maps, weather data, traffic conditions, and alternative routes.

With the improvements made possible by ITS deployment, the passenger automobile probably will continue to dominate transportation in the United States. However, the passenger car will go through some marked changes over the next 20 to 30 years. More fuel-efficient gasoline powered cars will be joined by hybrid diesel-electric vehicles, alternatively fueled vehicles, and fuel cell powered vehicles. The market for automobiles may partition, based on trip lengths and purposes. Electric cars and station cars, powered by advanced or conventional electric batteries, as well as solar-powered and people-powered personal vehicles, will assist commuters to perform local errands or economically reach transit system suburban collection terminals. These will complement larger vehicles, which will be used for longer trips, or when additional carrying capacity is needed. Both types of vehicles should be lighter and safer than current autos, as vehicle structures use more new plastics and composite materials.

Application of improved understanding of human performance and behavior, vehicle crashworthiness, and biomechanics, coupled with the structural improvements noted above, will help mitigate crash impacts substantially. However, most of the systems to improve safety will be introduced as equipment on new vehicles. The integration of new systems on a fleetwide basis may take 10 to 20 years from initial introduction of the technology. The average age of vehicles in the fleet is increasing, as more solid construction and reduced needs for maintenance permit consumers to retain their vehicles longer. Overall safety statistics will improve, but may not fully reflect the benefits of new crash avoidance/mitigation techniques at once.

Personal commuting and family pleasure travel will have many more real-time travel planning, scheduling, and routing options, due to intelligent recreational vehicles, advanced public transportation systems, and automated highway systems. The safety of personal travel and commercial vehicle operations will be ensured by advanced incident management and onboard collision avoidance radars, as well as intelligent cruise control. Speech recognition software will allow drivers to make vehicles comply by asking for the change. In-car navigation and information systems will be commonplace, integrated directly at all times and in all weather, and small video cameras may substitute for items like rearview mirrors. Intelligent driver trainers and simulators will be used to prepare and test for driver licensing and sobriety testing, as well as for safety recertification.

For intercity trips, there should also be fully automated highways, allowing high-speed auto travel with minimal driver intervention on selected routes. These may be separate highways, or lanes on existing/expanded highways reserved for vehicles with the appropriate high-speed control packages. The intelligent infrastructure for these highways will be compatible with, and possibly integrated into, multimodal traffic control systems directing aviation and maritime movements.

Public transportation systems will provide widely available, inexpensive alternatives to the personal vehicle for shorter trips. The recent emphasis on "smart growth" and "livable communities" will promote new human-scale developments that are designed to be served by local circulation and transit systems. Shuttle services will link these complexes with intercity modes for longer trips among clusters of development.

Computer dispatched paratransit vehicles serving the suburbs and elderly and disabled passengers will integrate with, and share HOV lanes with, advanced technology urban and intercity transit buses in more densely developed areas. Specialized and public transit services will reach into rural and lower-density areas, linking their carless residents to urban services. Many of these options will be powered using alternative fuels or use fuel cells.

The transit systems will profit from the technologies of the intelligent transportation infrastructure, with safety and performance improvements in bus vehicle maneuvering, merge collision avoidance, forward collision avoidance, and docking. Automatic vehicle location systems will be commonplace, with positions monitored from metropolitan scale traffic management centers. Real-time information on actual bus positions and schedules should be readily available to potential riders. With an increasing number of elderly riders, these systems will exemplify the "human centered design" concept.

# High-Speed Ground Transportation

High-speed, ground transportation is a self-guided intercity passenger transportation mode that is time-competitive with air and/or auto for trips of 100 to 500 miles. This form of transportation has been a prevalent phenomenon outside of the United States, with the French National Railways' TGV, Germany's ICE train, and Japan's Shinkansen train having long been leaders in high-speed ground transportation.

From the mid-1950s to the mid-1970s, intercity passenger trains lost more than three-fourths of their traffic base; high-speed services such as the multiple fast schedules between Chicago and the Twin Cities disappeared, and much of the passenger infrastructure deteriorated or was scrapped. Amtrak, which was created in 1971, was establishing itself from the passenger services, equipment, and facilities it had inherited from its predecessor railroad companies.

In 1975, corridor-type passenger service with top speeds of 90 miles per hour (mph) or greater existed on the Northeast Corridor main line, on two Northeast Corridor extensions, and on former Santa Fe Railway trackage in Southern California. However, no federal funding was available or proposed for high-speed rail corridors beyond the Northeast Corridor main line.

Under the High-Speed Ground Transportation Act of 1965, a partnership between the federal government and the Penn Central Transportation Company had created two major demonstrations of incremental high-speed rail technology later operated by Amtrak:

1. Metroliners, which offered schedules of three hours between New York City and Washington over old tracks and other fixed facilities; and

2. Turbotrains, which provided a somewhat improved service between New York and Boston over the antiquated former New Haven Railroad.

In 1975, the Northeast Corridor main line was about to receive what amounted to nearly $3.3 billion (by the end of 1980s) in federal fixed-facility investments to implement the recommendations of the Northeast Corridor Transportation Project for improved high-speed rail service between Washington, New York, Boston, and intermediate points [USDOT FRA 2000b].

High-speed service also was offered on two analogous routes in the 100- to 150-mile range, each linking a state capital with the state's largest city. The first ran over 104 miles of former Pennsylvania Railroad trackage between Philadelphia and Harrisburg, Pennsylvania. The second covered 145 miles of former New York Central Railroad trackage between New York City and Albany, New York. A third line in California, Santa Fe's 129-mile Surf Line, provided 90-mph service between Los Angeles and San Diego [USDOT FRA 2000b].

The federally funded Northeast Corridor Project provided the Washington–New York–Boston main line with a largely new infrastructure. The project realigned curves; upgraded track structure, including concrete ties; installed a new train control system with centralized traffic and electrification control; renovated stations; built new equipment shops; eliminated most highway grade crossings; and installed a new electrification system between New Haven and Boston, permitting fully electrified operation along the Boston–Washington right-of-way.

Amtrak

The Acela train, capable of reaching speeds of 150 mph, will provide an unprecedented high quality of service within the Northeast Corridor.

The original Metroliners and Turbotrains have been replaced by a new generation of locomotive-hauled trains. A third generation of Acela luxury equipment is in service on the Northeast Corridor. Reliable daily operation achieves 150-mph top speeds [USDOT FRA 2000b].

Progress also occurred on the two high-speed extensions of the Northeast Corridor. In the 1990s, New York State, Amtrak, the localities, and the federal government invested nearly $300 million in upgrading and re-equipping the Albany to New York portion of the Empire Corridor.

California, meanwhile, made significant investments in the Los Angeles to San Diego Surf Line as part of a program in the 1990s to upgrade and re-equip its entire Amtrak network, including lines linking Southern California, the Central Valley, the Bay Area, and Sacramento. About two-thirds of this $2 billion investment was state financing; the rest came from Amtrak, the localities, the freight railroads, and various federal sources. California plans a $300 million additional investment early in the 2000s [USDOT FRA 2000b].

Today, high-speed ground transportation options fall into three groups: accelerated rail service over existing railroads (Incremental High-Speed Rail [HSR]), new high-speed rail systems (New HSR); and magnetic levitation (Maglev), in order of increasing performance capabilities and initial cost (box 6-5).

The 1998 TEA-21 transportation legislation authorized a Magnetic Levitation Transportation Technology Deployment Program with $55 million for high-speed Maglev construction planning and up to $950 million authorized for construction of a single Maglev project [USDOT FHWA 1998]. In 1999, the federal government initiated a competition to select the best Maglev project for the purpose of demonstrating the use of Maglev technology, with selection slated for 2001 and design and construction for 2002 [USDOT FRA 2000a].

Incremental HSR has shown significant evolution since 1975 and is poised for still more expansion in the 21st century. In the 1990s, sizable federal commitments were made for HSR development outside the Northeast Corridor main line. The transportation reauthorization bills of 1991 and 1998 had established and expanded a program to federally designate high-speed corridors (figure 6-8). Among the corridors that had applied for designations and future funding as high-speed corridors as of early 2000 were lines between Chicago and Cleveland; Cleveland, Columbus, and Cincinnati, Ohio; and Boston, Massachusetts, and Portland, Maine.

Box 6-5

**Types of High-Speed Ground Transportation**

**Incremental HSR** consists of upgraded intercity rail passenger service on existing railroad rights-of-way, most of which belong to the freight railroads. Incremental HSR options may have top speeds ranging from 90 to 150 mph and may be electrified (powered by electricity distributed to locomotives through overhead wires) or non-electrified (powered by on-board generators).

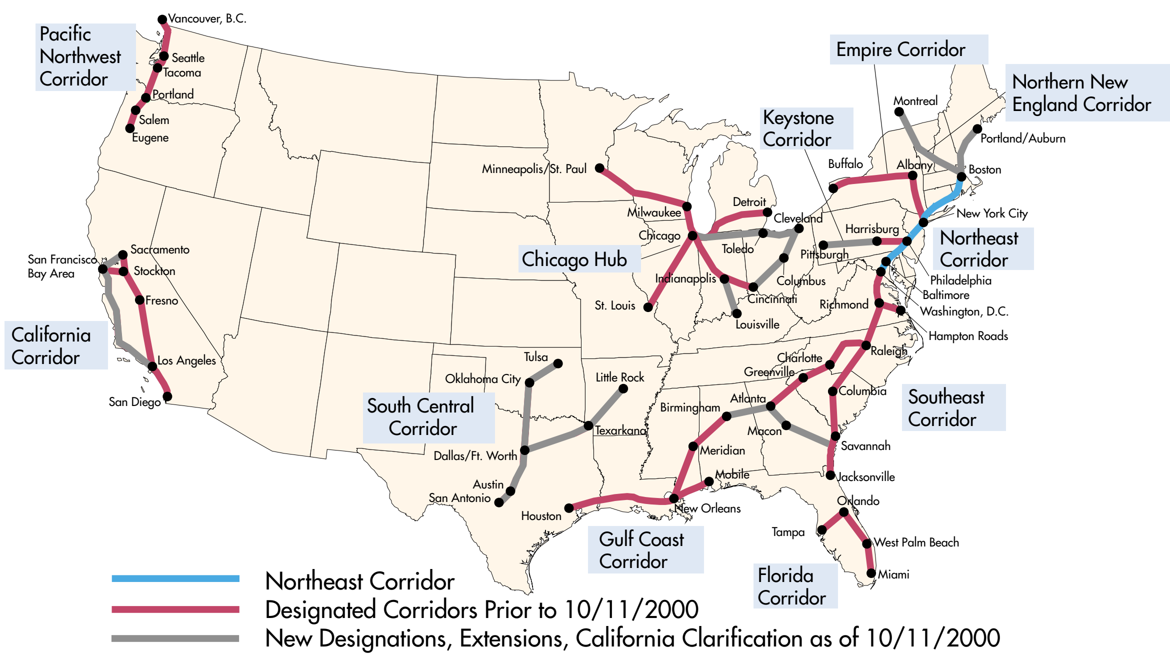
**New HSR** represents advanced steel-wheel-on-rail passenger systems on largely new rights-of-way. Through a combination of electrification and other advanced components, expeditious alignments, and state-of-the-art rolling stock, new HSR can attain maximum practical operating speeds on the order of 200 mph. However, because the trains are still able to operate on existing track, new HSR can combine new lines with existing approaches to urban terminals. The ability to operate over existing rights-of-way at their prevailing speeds, as well as on new routes, means that service can be extended beyond the New HSR line to other cities.

**Maglev** is an advanced transport technology in which magnetic forces lift, propel, and guide a vehicle over a specially designed guideway. Using state-of-the-art electric power and control systems, this configuration eliminates the need for wheels and many other mechanical parts, thereby minimizing resistance and permitting excellent acceleration, with cruising speeds on the order of 300 mph or more. This high performance would enable Maglev to provide air-competitive trip times at longer trip distances than other high-speed ground transportation options.

Source: U.S. Department of Transportation, Federal Railroad Administration, *High Speed Ground Transportation for America* (Washington, DC: September 1997).

Figure 6-8

**Designated High-Speed Rail Corridors: 2000**




Source: U.S. Department of Transportation, Federal Railroad Administration, personal communication, October 2000.

The 1990s also saw a renaissance of technology development for HSR. This Next-Generation High-Speed Rail Development Program addressed specific subsystems for enhancing the safety and affordability of HSR. These systems included:

- turbine-powered high-speed locomotives,
- radio-based positive train control,
- new cost-effective grade crossing solutions, and
- better riding, lower cost track and structures.

## Keys to the Future

If state and Amtrak interest in high-speed rail continues to grow, then corridors in many regions of the nation could provide significant high-speed train service by 2025. In particular, by 2025, all of today's designated corridors would have Amtrak service at 90 mph or better. These corridors will bring high-speed rail service to 150 million people living in metropolitan areas, nearly 75 percent of the metropolitan population. There could also be other lines, such as the additional Chicago Hub lines under consideration by the Midwestern consortium, parts of the Texas Triangle, or one or more of the lines for which designation applications were pending as of December 31, 1999.

To the extent that high-speed rail takes hold, the public would obtain benefits from airport and highway congestion reduction and from reduced air pollution. The extent of these benefits for a group of eight illustrative corridors is analyzed in a federal report, *High-Speed Ground Transportation for America* [USDOT FRA 1997].

By 2025, the next generation HSR technologies will mature to support reliable, cost-effective systems with superb service quality:

- nonelectrified corridors working at 125 to 150 mph,
- train control in place nationwide for productivity and safety,
- virtually all crossings eliminated on rail routes with significant traffic, and
- infrastructure delivering superb ride quality at low cost.

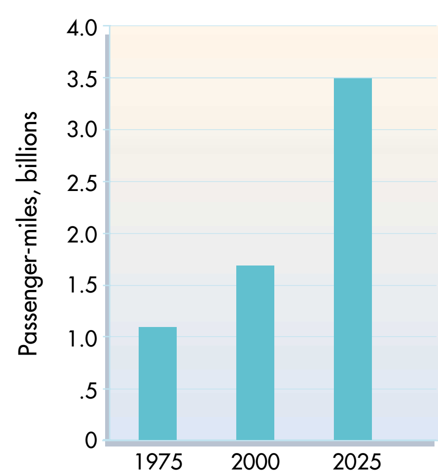
HSR's inherent advantages, particularly its connectivity with commuter rail and urban transit systems, could be fully realized, offering seamless transportation to a growing clientele.

HSR investments can yield significant benefits in terms of transportation production. For example, in the Northeast Corridor, traffic growth estimates project that high-speed rail will generate 3.5 billion passenger-miles annually by 2025, up from about 1.1 billion in 1975 and 1.7 billion in 2000 (figure 6-9). The *High-Speed Ground Transportation for America* report shows the expected growth in annual passenger-miles for typical corridors outside the Northeast Corridor main line (figure 6-10).

The first Maglev project in the United States could be operating in revenue service by 2010 if funds are appropriated. Beginning with a short demonstration, it could point to longer intercity systems in very high-density corridors. In fact, the *High Speed Ground*

**Figure 6-9**

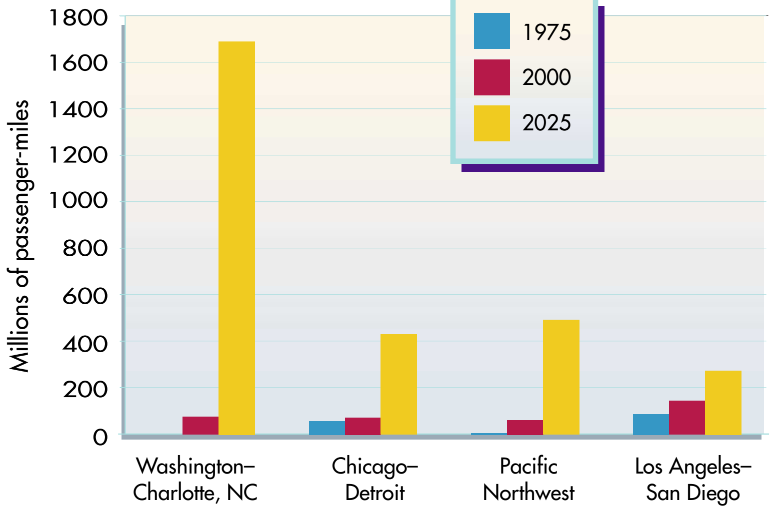
**Projected Growth in Passenger-Miles in the Northeast Corridor: 1975-2025**




Source: U.S. Department of Transportation, Federal Railroad Administration, *High-Speed Ground Transportation for America* (Washington, DC: 1997).

Figure 6-10

Projected Growth in Passenger-Miles Outside the Northeast Corridor: 1975-2025




Source: U.S. Department of Transportation, Federal Railroad Administration, *High-Speed Ground Transportation for America* (Washington, DC: 1997).

*Transportation for America* report found that Maglev could have the potential to bring about public-private implementation partnerships in the nation's two highest density corridors: the Northeast Corridor and California. Maglev could capture two-fifths of the existing airline market in California and generate almost six billion passenger-miles by 2025. In the Northeast Corridor, Maglev could capture about two-fifths of the remaining air market in the Northeast Corridor—about half the New York-Washington air/rail traffic currently uses Amtrak—and would generate about five billion passenger-miles per year in 2025.

It also is possible that Maglev would induce a heavy volume of completely new traffic, given the unusually short travel times it would permit between the major Northeast Corridor cities. By offering a new level of ground transportation service, a 300-mile-per-hour Maglev system in a major corridor would divert significant traffic from existing airports and highways. This would result in reduced congestion delays and emissions and would also reduce the need to expand air and highway facilities.

## Railroad System Technologies

Over the last quarter century, the traffic on our railroad system has continued to increase, both for passenger travel and freight movement. However, the extent of the rail system has not changed substantially, which has led to congestion on the system and caused safety-related concerns. Use of advanced communication, information, and navigation technologies can help enhance efficiency, capacity, and safety of the existing railroad system.

Typical railroad locomotives produced in 1975 were 3,600 horsepower diesel-electrics with direct current (DC) traction motors [USDOT FRA 2000c]. Continuous welded rail was just entering into widespread application, and wooden ties were used under all trackage. The typical freight car had a 70-ton carrying capacity, although 100-ton cars had just been introduced; all freight cars were made of steel. Unit trains were operated on only a limited number of routes. Only about one-third of the track network was signalized, and microwave radio communications systems had been installed primarily on the western railroads [USDOT FRA 2000c]. Improved understanding of train-track interactions was just emerging, and typical, state-of-the-art rail safety technology entailed improved visibility of locomotives and audible horn signals at intersections.

More than half of the nation's intercity passenger service had been discontinued four years earlier. Amtrak, successor to the private railroads for intercity passenger service, was purchasing locomotives that could be readily put into freight service when passenger train service ended. Self-propelled, electric Metroliner cars were in use on the Northeast Corridor, and a few Turbotrains were in service for medium-speed runs on a few passenger corridors, but these required excessive maintenance.

Today, typical locomotives produced are 6,000 horsepower diesel-electrics with alternating current (AC) traction motors. The typical freight car has a 125-ton carrying capacity, and larger cars are being considered; many of the new freight cars have aluminum car bodies. Continuous welded rail is in place on virtually all mainlines, and concrete ties have been installed on the heaviest density lines. Additionally, half of the rail network is now signalized. Unit trains carry nearly half of the freight revenue ton-miles.

Amtrak has invested in new, high-speed trainsets that are capable of providing 150-mph service on the Northeast Corridor between Washington and Boston [USDOT FRA 2000c]. A number of states, including California, Illinois, Michigan, New York, North Carolina, Ohio, Oregon, Virginia, Washington, and Wisconsin are establishing high-speed passenger corridors on existing rail lines. States also are increasingly pursuing the development of new high-speed corridor services to reduce congestion on highways and at airports. The result is a greater combination of freight and passenger trains on common tracks, raising new safety concerns.

A key solution for many of these issues is digital communication technologies. The USDOT and the railroad industry are examining ways to develop Intelligent Railroad Systems that would incorporate the newest digital communications technologies into train control, braking systems, grade crossings, and defect detection (box 6-6). The new communications-based train control systems are a key element in making the railroad system safer and new intercity passenger services both safe and economically viable. New electronic sensors and transmission systems will help railroads achieve the long sought-after goal of advanced detection of hazardous conditions in equipment and track.

**Box 6-6**

**Intelligent Railroad System Technologies**

*Nationwide Differential Global Positioning System (NDGPS),* an augmentation of the GPS, provides one-to-two-meter positioning accuracy to receivers. NDGPS receivers will be placed on locomotives and maintenance-of-way vehicles, and their locations will be transmitted back to control centers over a digital data link communications network. NDGPS is now operational for more than 80 percent of the continental United States and is scheduled to be fully operational in 2004.

*Positive Train Control (PTC)* systems are integrated command, control, communications, and information systems for controlling train movements with safety, precision, and efficiency. PTC systems bring together digital data link communications networks, continuous and accurate positioning systems such as NDGPS, on-board computers on locomotives and maintenance-of-way equipment, in-cab displays, throttle-brake interfaces on locomotives, wayside interface units at switches and wayside detectors, and control center computers and displays. PTC systems will improve rail safety by significantly reducing the probability of collisions between trains, casualties to roadway workers, damage to equipment, and overspeed accidents.

*(continued on next page)*

Box 6-6 continued

**Intelligent Railroad System Technologies**

*Electronically controlled pneumatic (ECP) brakes* use an electronic signal along an on-train communications network to initiate brake applications and releases and, thereby, permit the simultaneous application of all brakes on a train, substantially shortening braking distance. They are an advance over current train braking systems that use air to both power the brakes and initiate brake applications and releases. As with PTC, this technology already exists, but is not yet widely deployed.

*Automatic Equipment Identification* tags have been installed on all U.S. and Canadian freight cars and locomotives since 1995. Electronically reading these tags enables railroads to know the precise location of every locomotive, car, and shipment at all times.

*Wayside equipment sensors* can identify defects that can occur on passing trains so they can be stopped for necessary repairs. Among the defects that can be detected by wayside sensors are overheated bearings and wheels, deteriorating bearings, cracked wheels, derailed wheels, and excessively high and wide loads.

*Locomotive internal health monitoring systems* consist of sensors mounted on locomotive engines; electrical, air, and exhaust systems; and fuel tanks. These sensors communicate over the digital link network to permit real-time monitoring of locomotive performance at control centers and maintenance facilities.

*Car onboard commodity component sensors* can monitor the status of the commodities being carried and identify a number of car defects. This information can be transmitted over the ECP brake communications channel and digital link to train crews, control centers, and maintenance facilities.

*Intelligent grade crossings* use information gleaned from PTC systems to provide information on train presence and arrival times to motorists and information on a vehicle stalled in the middle of a grade crossing to railroad control centers. This information could dramatically reduce grade crossing collisions nationwide.

*Intelligent weather systems*, combining a network of local weather sensors and instrumentation with forecast data, will alert train control centers and crews of hazardous weather and the potential for dangers such as flooding, track washouts, or avalanches.

*Tactical traffic planners* produce plans showing when trains should arrive at each point on a rail line, where they should meet and pass, and which trains should take sidings. These plans complement the activities of PTC systems.

*Strategic traffic planners* serve as the highest-level real-time control system in the PTC control hierarchy, analyzing schedule and performance data to maximize safety and efficiency.

*Freight car reservation and scheduling systems* allow customers to reserve freight car capacity and routing, allowing railroads to better schedule their cars. These systems, similar to airline reservation systems, reduce shipping of empty cars, and reduce delays to loads and empties at intermediate yards. They also reduce fleet size requirements and improve asset utilization.

Source: U.S. Department of Transportation, Federal Railroad Administration, Working Paper on Railroad System Technology, draft, Washington, DC. March 2000; personal communication, Federal Railroad Administration, Office of Railroad Development, October 2000.

# Aviation Technology

The U.S. National Airspace System (NAS) is the largest, busiest, most complex, and most technologically advanced aviation operation in the world (box 6-7). The FAA provides the NAS infrastructure to support all air operations within the United States and certain ocean regions. FAA responsibility extends from air traffic control (ATC) to aviation safety and security and international coordination.

Box 6-7

**What is NAS?**

The National Airspace System (NAS) is a complex collection of facilities, systems, equipment, procedures, and airports. It includes more than 18,770 airports, 21 air route traffic control centers, 194 terminal radar approach control (TRACON) facilities, more than 467 airport traffic control towers, 76 flight service stations, and approximately 4,533 air navigation facilities. More than 34,000 pieces of maintainable equipment, including radars, communications switches, ground-based navigation aids, computer displays, and radios are used in NAS operations. NAS operates nonstop, 24 hours a day, 365 days a year.

Source: U.S. Department of Transportation, Federal Aviation Administration, *FAA Administrator Fact Book* (Washington, DC: December 1999).

U.S. commercial aviation has been growing rapidly over the last quarter century and is projected to grow even faster during the next 25 years. To accommodate this growth and to enhance current safety and efficiency levels, the FAA is engaged in a comprehensive program to modernize the ATC system. This includes replacing radar surveillance systems; modernizing voice communication systems; and introducing enhanced automation aids, data links, and improved weather systems.

In addition to ATC modernization (which will safely and efficiently move the increasing air traffic and reduce congestion in the skies), new aircraft technologies are under development that will allow better use of existing infrastructure capacity.

During the 1970s, the ATC infrastructure needed to handle this growth in demand also needed modernization. At that time, the ATC system was a combination of equipment, techniques, procedures, and skills that had evolved over the previous four decades. On one hand, it was the safest, most efficient ATC system in the world. On the other hand, it was very expensive to operate and maintain; expansion capability was limited at major airports; and adaptability to evolutionary change was constrained.

By 1973, the NAS "En Route Stage A" Phase One modernization had been completed. This was a decade-long program to automate and computerize the nation's en route air traffic control system for commercial aviation. All 21 air route traffic control centers in the United States gained the capability to automatically collect and distribute information about each aircraft's course and altitude to all of the sector controllers along its flight path.

General aviation and military pilots still had to file flight plans at flight service stations and military operations offices, but computers would then handle the centers' "bookkeeping functions" of assigning and printing out controller flight strips. The new computers also had the ability to record and distribute any changes registered in aircraft flight plans en route. Eventually, the system was tied in with the new Automated Radar Terminal Systems being installed at major airports. In 1975, phase two of the En Route Stage A automation program provided controllers at the 21 air route traffic control centers with new radar displays, which provided vital flight information, such as altitude and speed, on the screen.

During the last 25 years, the federal government has made impressive strides in its technology planning methodology and approaches. It has encouraged NAS users (airlines, pilots, U.S.

military, and general aviation) to become part of the planning process to ensure needed system improvements are identified early.

In 1981, the federal government released the first *National Airspace System Plan*, which resulted from an intensive 10-month study of NAS needs. The plan described a comprehensive approach for modernizing and improving ATC and airway facilities services through 2000. In parallel, the federal government completed the *National Airspace Review* in collaboration with industry. This study of the operational uses of the nation's airspace included ATC procedures, flight regulations, and the airspace environment.

The NAS plan addressed the problems of how best to accommodate the increasing demands for aviation services while constraining costs, recasting the required technical framework, and replacing aging facilities. It delineated specific improvements to facilities and equipment and described needed research and development to support NAS. Particular emphasis focused on terminal and en route air traffic control, flight service stations and weather services, ground-to-air services, and interfacility communications, as well as auxiliary services.

In 1991, the annual *Capital Investment Plan* was introduced to replace the *National Airspace System Plan.* The *Capital Investment Plan* incorporated *National Airspace System Plan* projects, more than 86 percent of which had been completed or were in field implementation by that time. It also added new projects that were identified as mission-critical. Essentially, the CIP recognized that NAS modernization was not a one-time upgrade of the NAS, as some had interpreted the NAS Plan, but rather a phased implementation with a continuing set of capital investments needed to maintain and sustain NAS performance in an evolutionary way (which administrator Garvey termed as "Build a little, test a little.") to meet the continued growth of aviation and the changing aviation business environment.

***"It took 45 years to reach a world fleet of 13,000 jets. That number should double in the next 16 years. In the 12 years from 1970 to 1982, the number of passengers carried by airlines around the world doubled to 750 million. Sixteen years later, in 1998, that number doubled again to over 1.5 billion passengers…more than the population of China. And by 2016, when The Boeing Company will be 100 years old, traffic will double again to three billion. Both airports and the Air Traffic Management system must contend with significant fleet and passenger growth in the years ahead."***

**Philip M. Condit**
Chairman and Chief Executive Officer
The Boeing Company
Aviation in the 21st Century: Beyond Open Skies Ministerial
Chicago, IL Dec. 7, 1999

Despite the growth in air traffic, only one major new airport has been built in the past 25 years: Denver International Airport, which opened in 1994. The expansion of existing airports has been slowed by a variety of concerns, ranging from cost, to limited space, to noise and other environmental considerations. To better use existing capacity, the federal government has sponsored an aggressive investment program to carry out the *Capital Investment Plan* and modernize the ATC system. As a result, major technological improvements have taken place in NAS functional areas: communications, navigation, surveillance, weather information, automation, and facilities and associated systems. The advancements made in each of these functional areas are discussed below.

**Communications:** In 1975, the NAS was characterized by vacuum-tube-type electronic equipment that frequently failed and was costly to maintain. In ATC communications, leased point-to-point lines for interfacility communications were the rule. These lines were costly and provided little flexibility. For air-to-ground communications, multiple, overlapping radio sites and archaic switching systems in ATC facilities impeded controllers' ability to serve system needs. Box 6-8 shows some important communication technologies implemented in the last 25 years.

Box 6-8

**Communication Technologies**

- **Interim Voice Response System:** This system, installed in 24 cities by 1985, made weather information available to pilots using a touch-tone telephone.

- **Consolidated Notices to Airmen (NOTAM) System:** Activated in 1986, the Consolidated NOTAM System collects, processes, and distributes messages to aviators throughout the United States and abroad.

- **Voice Switching and Control System/Enhanced Terminal Voice Switch:** These systems replaced older, electromechanical communications systems. They provide controllers with faster, more reliable, and more economical computer-controlled communications with aircraft and other ATC facilities.

- **Aeronautical Data Link (ADL):** Data link is intended to establish an alternative link between pilots and controllers to relieve voice congestion and some of the problems introduced by sole reliance on voice communications. The first phase of Aeronautical Data Link is Tower Data Link Services (TDLS). Fifty-seven airports/terminals have been completed and operational with TDLS as of 1997.

Source: U.S. Department of Transportation, Federal Aviation Administration, *Blue Print for NAS Modernization* (Washington, DC: January 1999).

**Navigation:** The NAS relies on a system of ground-based navigational aids. These aids cannot provide complete area navigation throughout United States at low altitudes. While the long-term solution is a complete conversion to satellite-based navigation with greater reliance on GPS, there have been many interim capital investments to sustain performance. The current aviation navigation system is comprised of more than 4,000 ground-based systems whose signals are used by aircraft avionics for en route navigation and landing guidance. Despite the large number of ground systems, navigation signals do not cover all airports and airspace. Some navigation technologies are described in box 6-9.

Box 6-9

**Navigation Technologies**

- **Loran-C:** The USCG-operated Loran-C navigation system was adapted for civil aviation use in 1986. Loran-C became a supplementary system for aviation, and the "mid-continent gap" in navigation was closed in 1991 through construction of several new stations.

- **Very High Frequency (VHF) Omni-Directional Radio Range:** The first of a new generation of navigational aids was commissioned in 1982 to replace vacuum tubes with more reliable solid-state equipment. By 1985, 950 sites had been upgraded. Today, this technology remains the backbone of the nation's aviation navigation system, pending transition to GPS-based navigation.

- **Precision Approach Path Indicator:** Adopted internationally in 1982 to replace the older Visual Approach Slope Indicator, the Precision Approach Path Indicator gave pilots an indication of the extent of their deviation from the intended glide path, rather than merely warning that they were too high or too low. By 1997, 237 systems were installed at international runways at U.S. airports.

Source: U.S. Department of Transportation, Federal Aviation Administration, *Blue Print for NAS Modernization* (Washington, DC: January 1999).

**Surveillance:** Surveillance systems provide positional data of aircraft in U.S. airspace, on the airport surface, and over the ocean. These are important to prevent mid-air collisions and for safe aircraft operations. In 1975, NAS surveillance was based on a mixture of primary ("independent") radars and secondary ("dependent") radars, called ATC radar beacons, in the en route and terminal areas of the United States. In many areas (e.g., oceanic, remote, low altitudes, and airport surfaces), there was no surveillance coverage. The *National Airspace System Plan* envisioned that a new, secondary radar system would interrogate aircraft transponders on an individual basis, paving the way for automatic data link air-ground communications on the same system. This system, known as "Mode-S," has not yet been fully implemented. Some surveillance technologies are described in box 6-10.

**Box 6-10**

**Surveillance Technologies**

- **Mode-C Intruder Capability:** In 1973, the federal government required aircraft flying in designated areas to carry an improved radar beacon transponder with automatic altitude reporting capability, as well as the ability to transmit identity codes. This rule was designed to reduce the potential for mid-air collisions.

- **Mode-C Conflict Alert:** In 1978, the federal government installed conflict alert capability at selected facilities to give controllers early warning of potential mid-air collisions.

- **Precision Runway Monitor:** In 1989, the federal government began testing a new Precision Runway Monitor radar that increased the frequency with which aircraft movements were updated on air traffic controllers' screens, thereby improving their accuracy and ability to prevent collisions. Three systems were operational by 1999, and two remaining systems are due for completion in 2001.

- **Mode-S Radar:** First tested in 1991, Mode-S production systems have been implemented in 144 locations across the country. They provide the foundation for the next generation Monopulse beacon radars, which provide aircraft position information faster than the older radar beacon systems.

Source: U.S. Department of Transportation, Federal Aviation Administration, *Blue Print for NAS Modernization* (Washington, DC: January 1999).

**Weather:** Weather is a critical aspect of aviation safety, responsible for 65 percent of all delays and 40 percent of all crashes. Over the last 25 years, the federal government has made breakthroughs to achieve significant improvements in weather-related technology.

Perhaps the greatest weather-related progress has been made in reducing the threat of windshear—which is a sudden and dramatic shift in wind speed and direction. Its most dangerous manifestation is in the phenomenon of "micro-bursts." Micro-bursts occur when severe thunderstorms induce a rapid, downward movement of air that can destabilize aircraft, especially when they are in their final descent to an airport. The Terminal Doppler Weather Radar program and the Low-Level Wind Shear Alert System have been very effective in helping pilots and controllers maneuver around trouble spots. Combined with pilot training and on-board windshear detectors, these technologies have reduced the threat from windshear. Some of the weather information technologies are described in box 6-11.

**Automation Systems:** The NAS is a very large and complex command-and-control system. In this system, information from the diverse sensor systems (surveillance, navigation, and weather) are routed to air traffic control facilities by a robust communications system. In the facilities, automation systems analyze, process, and display this sensor data to controllers, who then work with pilots and others to establish and maintain a smooth, safe, and efficient air transportation flow throughout the NAS. Thus, automation systems are crucial to system effectiveness, and they have been a major focus of investment during the past 25 years. Automation technologies are described in box 6-12.

Box 6-11

**Weather Information Technologies**

- **Terminal Doppler Weather Radar:** The Doppler effect permits an object's or air masses' speed and direction to be determined. Based on studies conducted in 1983 and 1984, the Terminal Doppler Weather Radar program was designed to produce warnings on dangerous windshear micro-bursts at airports. First operational in 1994, Terminal Doppler Weather Radar was deployed at 43 sites nationwide by 1999.

- **Low-Level Wind Shear Alert System:** First operational in 1978, and expanded to 110 airports, the Low-Level Wind Shear Alert System detects wind changes associated with wind shear by means of multiple sensors that measure wind speed and direction at several locations around the airport. It assists in safe landing and takeoff operations.

- **Next-Generation Weather Radar:** Using the Doppler effect, Next-Generation Weather Radar can "see" inside storms and measure the velocity and direction of wind-driven precipitation. The entire system of 158 Next-Generation Weather Radars was completed between 1994 and 1999.

Source: U.S. Department of Transportation, Federal Aviation Administration, *Blue Print for NAS Modernization* (Washington, DC: January 1999).

Box 6-12

**Automation Technologies**

- **ARTS IIIA Upgrades:** Beginning in 1976, ARTS III radar installations were upgraded to an ARTS IIIA configuration to provide radar tracking of aircraft not equipped with transponders. Completed by 1985, this system enables automatic reporting of aircraft identity and altitude. An upgraded ARTS IIIE system with greater capacity is now being installed.

- **Minimum Safe Altitude Warning:** First commissioned in 1976, the Minimum Safe Altitude Warning system was an add-on computer feature that could warn controllers of unsafe conditions by automatically monitoring aircraft altitudes and comparing them to terrain maps stored in the computer's memory.

- **ARTS II Systems:** Designed for airports that did not warrant the more costly and highly automated ARTS III, the ARTS II, installed at 120 smaller airports beginning in 1978, enabled full tracking of transponder-equipped aircraft.

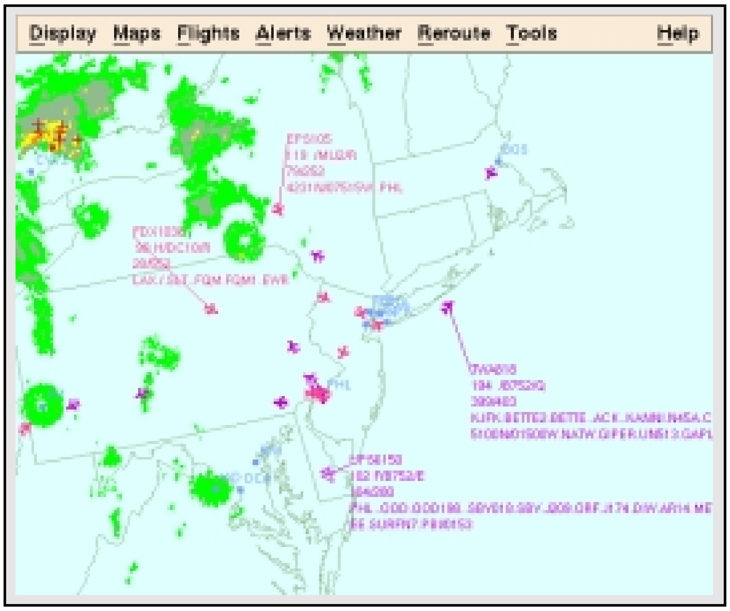
- **Display System Replacement:** Begun in 1996 and completed in 2000, Display System Replacement provides new, automated workstations and color displays for controllers at all en route centers.

- **Standard Terminal Automation Replacement System (STARS):** Begun in 1996 after termination of the Advanced Automation System, STARS includes new computers, displays, and software for air traffic control facilities. The first deliveries of partial, new operational systems began in 1999.

Source: U.S. Department of Transportation, Federal Aviation Administration, *Blue Print for NAS Modernization* (Washington, DC: January 1999).

**Facilities:** In 1975, there were many individual ATC facilities with large overhead costs. Consolidation of ATC services in large metropolitan areas can generate significant safety, operational, and economic advantages. The first Consolidated/Large TRACON Facility was located in the New York City area, where it serves several major airports. Consolidation also has been completed in Southern California and is being undertaken in several metropolitan areas across the country.

The National Air Traffic Control System Command Center was established at Washington, D.C., in 1970. Periodic upgrades, such as Aircraft Situation Display (1987), Monitor Alert




USDOT, FAA

Using the Enhanced Traffic Management System (ETMS), air traffic controllers are able to monitor incoming and outgoing flights. The picture shows an ETMS screen display for four airports in the Northeast region (JFK, Philadelphia, Pittsburgh, and Boston Airports) with identities of various aircraft in the air space at a particular time.

(1987), and the Enhanced Traffic Management System (1990), have permitted greater ability to exercise real-time traffic flow management strategies in congested traffic conditions, especially during major storms.

## Keys to the Future

America's aviation industry is entering the 21$^{st}$ century with projected increases in business, recreation, and personal travel. U.S. airlines project they will carry twice as many passengers within the next 15-20 years as they do today [USDOT FAA 2000]. This increase will not only be at large metropolitan airports, since the growth of regional jet service also will increase traffic at smaller airports. To manage this increased load on the NAS, the ATC system and supporting services require coordinated, long-term technology modernization (box 6-13).

To ensure that ATC services meet increased demand and a changing environment, the federal government joined with the aviation community to develop a NAS modernization plan that identifies the capabilities needed by the NAS users and service providers in order to provide more efficient operations. This plan addresses the need for modernizing, deploying, and inserting new technologies into the NAS and improving services and capabilities during the first quarter of this century. The plan focuses on several key areas, which are discussed in the following paragraphs.

Box 6-13

**Future Aviation Technologies**

In his speech during the *Aviation in the 21st Century: Beyond Open Skies Ministerial* conference, Chicago, Illinois, on December 6, 1999, NASA Administrator, Daniel S. Goldin outlined many new technological developments that will allow aviation systems to meet today's needs and address future concerns. Among those concerns are safety, noise, air quality, and congestion at airports and in the skies. The technologies include:

- runway Independent Aircraft, which are "capable of takeoff and landing on whatever ground is available – independent of size and direction" and may reduce the need for additional runways;
- Final Approach Spacing Tool (FAST) and a wake vortex sensing and prediction system that can improve the number of safe takeoffs and landings;
- semi-buoyant airplanes capable of carrying large loads of cargo;
- development of self-diagnosing and self-repairing airplanes that could lessen the occurrence of repair oversights;
- development of planes that are equipped with embedded sensors for full-time and real-time situation awareness and are able to compensate for pilot stress and fatigue which can reduce pilot error;
- model-based reasoning and neural networks that will analyze abnormalities to help accurately diagnose problems that may occur during flight;
- development of artificial vision—an integrated system of advanced sensors, digital terrain databases, accurate geo-positioning, and digital processing that will provide a clear three-dimensional picture of terrain, obstacles, runway, and traffic, and can help pilots avoid a number of flight hazards; and
- full-scale annular combustors for jet engines that can improve air quality and reduce noise, which could increase the public's acceptance of airports in their neighborhoods;

Source: Excerpts from speech by Daniel S. Goldin, Administrator, National Aeronautics and Space Administration, Aviation in the 21st Century: Beyond Open Skies Ministerial Conference, Chicago, Illinois, December 1999.

**Communications:** Communications quality and reliability can be improved through integrated digital communications. This modernization requires replacement of outdated hardware, better use of the available VHF spectrum, and integration of systems into a seamless network using digital technology. During the transition, the federal government plans to continue to support analog communications.

For the past 20 years, demands on VHF spectrum for air traffic services have grown by an average of four percent per year, saturating the available spectrum in many locations. Transition to digital radios will effectively increase the capacity of each VHF frequency, by at least a factor of two.

Controller-pilot data link communications (CPDLC) will introduce data exchange between controllers and pilots to reduce voice-channel congestion. Data link is also expected to reduce the opportunity for missed communications or misinterpretations of the messages. Transition to data link communications will occur gradually as new applications are tested prior to national deployment and as users equip with the necessary avionics. CPDLC initially will provide two-way exchange of air traffic control messages, such as transfer of communications and altimeter settings that are currently conveyed by voice. Voice communications will continue to be available. Oceanic and en route use of data link will precede the use of data link in terminal airspace. Current airport data link operations, called pre-departure clearance, will continue to expand.

**Navigation:** GPS-based services can provide increased accuracy, operational safety, and airport coverage. Over the next 10 years, the navigation system is expected to use satellite-based services, augmented by ground monitoring stations, to provide navigation signal coverage throughout the NAS. Reliance on ground-based navigation aids is expected to decline as satellite navigation provides equivalent or better levels of service.

The transition to satellite-based navigation would depend on implementation of WAAS and LAAS, as described previously in the GPS section.

**Surveillance:** The NAS modernization plan calls for evolution from current primary and secondary radar systems to digital radar and automatic dependent surveillance. This change is designed to improve and extend surveillance coverage and provide the necessary flexibility for Free Flight. The FAA will continue to use primary and secondary surveillance radars to detect and track aircraft in en route and terminal airspace.

Surveillance in the future NAS will provide coverage in nonradar areas and include aircraft-to-aircraft surveillance capabilities for greater situational awareness and safety. An automatic dependent surveillance-addressable system (ADS-A) will provide surveillance of intercontinental flights in oceanic airspace. Once installed in the aircraft and on the ground, these capabilities and accompanying procedures will increase aviation safety and efficiencies while reducing procedural separation distances, thereby enhancing the airport capacity.

A new avionics capability, automatic dependent surveillance-broadcast (ADS-B), may be introduced that will provide higher capability surveillance services compared to today's radar-based surveillance.

**Weather:** NAS modernization includes improved methods for collecting, processing, and transmitting weather information during all phases of flight. The key to reducing weather-related incidents is to improve pilot decisionmaking by providing timely weather information. Service providers and users will simultaneously receive depictions of hazardous weather to improve their understanding of weather conditions.

Modernization of aviation weather forecasting systems will replace present-day separate, standalone systems with ones that are fully integrated into the NAS. The focus is on two key capabilities:

1. improved processing/display—systems critical to this capability are the Integrated Terminal Weather System and Weather and Radar Processor, both of which will be installed by 2002, and

2. improved sensors/data sources—featuring the Next Generation Weather Radar, Terminal Doppler Weather Radar, and ground- and aircraft-based sensors.

***"Every airplane in the system can know exactly where it is located and know the location of every other airplane. Every airport will have every runway effectively equipped with precision approach since there will be a universal satellite system rather than individual runway guidance systems. Every airport system could increase capacity without additional runways."***

**Philip M. Condit**
Chairman and Chief Executive Officer
The Boeing Company
Aviation in the 21st Century: Beyond Open Skies Ministerial
Chicago, IL
Dec. 7, 1999

**Avionics:** Avionics is the use of satellite-based navigation and digital communications to improve safety and efficiency. It will evolve to take advantage of the benefits found in the new communications-, navigation-, and surveillance-related technologies planned in NAS modernization. With the new avionics, users will have access to many enhanced services that will help them fly more safely and efficiently. The pace of modernization will be benefits-driven and dependent on users equipping the aircraft with these new avionics.

**Free Flight Phase I:** Free Flight Phase I, to be introduced by 2002, uses advanced airborne and ground based technologies and new procedures to permit the use of optimum tactical separation between planes, enabling more planes to fly and to take more efficient, more direct routes. An important objective of Free Flight Phase 1 is to mitigate NAS modernization risks by deploying operational tools at a limited number of sites to evaluate performance, training procedures, human factor requirements and solutions, and safety issues. Users and service providers will have the opportunity to assess system performance, operational benefits and acceptability, and safely before further deployment. With positive results, each Free Flight Phase 1 tool will be fully developed, integrated, and deployed to suitable locations. To date, Free Flight Phase 1 has been a complete success. Free Flight Phase 2 will build upon the success of Phase 1 and will alleviate congestion over a wider geographic area. The Phase 2 timeline extends from October 2000 through December 2005.

**Departures/Arrivals (Optimizing Aircraft Sequencing)**: Arriving and departing aircraft are sequenced in and out of the airport by air traffic controllers at the terminal radar approach control facilities. Providing controllers with tools for sequencing and spacing aircraft more precisely can ensure a steady flow of aircraft, particularly during peak periods. The objective is to reduce variability in services and optimize use of airspace and available runways. Focused on increasing airport capacity, terminal modernization will evolve through the installation of improved automation systems to provide technology and procedural enhancements.

With new capabilities inherent in advanced navigation and surveillance technology, departure and arrival procedures will change to reduce or eliminate speed and altitude restrictions and to allow aircraft to use a greater portion of the airspace around airports.

A new generation of advanced aircraft, using lighter and stronger materials and new propulsion concepts will replace today's aging commercial and general aviation air fleet. They will take advantage of the enhanced navigation, communication, and air traffic control system described previously.

Travelers will be able to make expanded use of small aircraft and small airports for business and personal intercity transportation, especially in lower density areas. NASA is working on the Small Aircraft Transportation System (SATS) initiative, which is intended to provide, by 2022, a system that will enable doorstep-to-destination travel at four times the speed of highways to 90 percent of the nation's suburban, rural, and remote communities. It includes expanding the number of public-use airports that are equipped for near all-weather operational support of SATS aircraft. SATS aircraft will encompass new avionics, airframe, engine, and pilot training technologies. These new technologies will create new features and capabilities that will significantly improve affordability, safety, and ease of use over today's aircraft.

The next generation of commercial aircraft will be safer, quieter, and environmentally compatible, as well as more efficient and customized to market niches (e.g., low fare, business, and tourist). Super-jumbo, wide-body jets may carry 800 passengers on routes serving the Pacific basin or major shuttle corridors, relieving air traffic congestion, yet accommodating growing global tourism demand. Such large airliners will be cleaner, quieter, and more fuel-efficient, but will also bring added challenges in security, baggage handling, and traffic management around airports they operate from.

Airport complexes (Reagan National, Washington Dulles, and Baltimore-Washington International; Newark; NY La Guardia, NY JFK International, and Islip/Mac Arthur; Manchester, NH; Boston, MA; and Providence, RI) serving heavily developed areas should continue to proliferate, with associated ground access problems as traffic levels rise. Inter-airport ground shuttles, Maglev systems, short-range air links, and better integrated intercity services may be used to lessen these pressures. These multimodal linkages, combined with improved weather forecasting and user-oriented ticketing systems, may reduce overall travel delays, and provide alternatives for travelers whose journeys are interrupted by adverse flight conditions.

Environmentally friendly supersonic and hypersonic aircraft with advanced noise and sonic boom reduction technologies will transport passengers and high value cargo more quickly. Tiltrotors, quiet helicopters, and other vertical take-off and landing (VTOL) agile small and light aircraft will rapidly carry and deliver intercity business travelers to the downtown to re-lieve airports, or to suburban destinations, replacing some corporate jets. These aircraft will incorporate "fly-by-light" technology and artificial cockpit vision (which fuses radar, infrared imaging, and video) for all-weather, 3-D situational awareness and the safety that comes with it.

In addition, tomorrow's aerospace transportation system must integrate the requirements of the emerging space transportation industry. Low-cost, user-friendly commercial space access is the key to the future of global telecommunications, safe navigation for all types of transportation vehicles, and operations of both civil and military transportation services. Current activities made possible by orbital platforms will become more inexpensive and expand: massive transmissions of voice communications and data will occur in real time, monitoring of changing weather and other conditions at the surface of the earth will improve; positioning and navigation services will become more accessible; and fleet management and parcel tracking will be facilitated. Commercial exploitation of space will continue with expanding telecommunications, new remote sensing applications, and medical complexes in orbit. There may be the first signs of a premium fare space and tourism industry. The presence of a permanent space station or lunar base should accelerate these trends.

Manned traffic into low earth orbits should increase substantially. The X-33/Venture Star and X-34 should lead to single-stage-to-orbit shuttles, which carry payloads directly into space, return to earth, and then are quickly recycled for their next mission. Low-cost, versatile launch vehicles, associated spaceports, and payload integration infrastructure will make the continued growth possible. Currently in testing are commercial launch vehicles with controlled re-entry characteristics to allow their re-use, and air-launched orbital vehicles which function as air-breathing space planes. In addition to orbital missions, these new classes of aerospace vehicles operating sub-orbitally could provide access to anywhere in the world in less than two hours to transport premium-fare passengers and high-priority freight.

## Maritime Technology

Major technological advances have occurred in the 1990s in vessel propulsion, navigation, positioning, charting, and traffic management. Studies have been conducted to investigate the feasibility of using fuel cells to provide shipboard electric power. Charting advances include the use of aerial photography to accurately annotate areas, such as the national shoreline, and the use of electronic devices and software to replace paper charts. Vessel traffic management systems route and monitor vessel traffic efficiently and safely through ports and other areas. Electronic navigation aids use satellites to provide real-time position information to mariners and to improve the safety of life and property. Following a century of major technological advances, today's challenge is to make these technologies compatible across many media and among the various modes of transport. Significant technological efforts will continue to be needed to reduce the introduction of aquatic nuisance species and to mitigate the effects of cruise ship discharges of sewage and wastewater.

**Navigation Aids:** Navigation aids can be grouped into two categories: short- and long-range. In the past, primary navigation was based on short-range aid, which included buoys and lighthouses, daymarkers, foghorns, and fog signals. Focus was on improvements in construction and maintenance of existing navigation aid technology. Lightships—unmanned small vessels equipped with lights—were still in operation, but were phased out in the early 1980s. Long-range navigation systems (LORAN) relying on a grid of low-frequency radio waves transmitted from ground-based stations located around the world provided accuracy within one quarter mile for both civil and military air, land, and marine users until the mid-1990s. Today, the satellite-based GPS provides reliable accuracy to within a few meters. A variety of electronic aids, ranging from direction-indicating beacons to satellites, have been used in radionavigation. The Radionavigation Aids Program, which manages and operates federal maritime radio aids, provides continuous all-weather navigation capability.

Application of new technologies to navigation and marking systems can improve overall mission performance by providing alternative, customized cues that allow users to navigate in a wider range of environmental conditions and situations. In the long term, if such a system could meet stringent reliability and availability standards, it could be argued that the physical hardware infrastructure could be eliminated, and the support fleet and personnel could then be deployed to other critical missions, providing improved resource allocation.

**Navigation Charts:** A chart is a working document used by the mariner both as a roadmap and worksheet, and is essential for safe navigation. In conjunction with supplemental navigational aids, it is used to lay out courses and navigate ships by the shortest and safest route. Federal law requires all ships in excess of 1,600 gross tons to have and use current editions of Navigational Charts or Coast Pilots produced by the National Oceanic and Atmospheric Agency's (NOAA) Office of Coast Survey. Environmental groups, academia, and coastal zone planners also use charts and hydrographic surveys.

By the middle of the 19$^{th}$ century, the Office of Coast Survey was using photography to shrink and enlarge a chart's scale and had developed a process that allowed engravers to make an infinite number of copper printing plates from a single engraved master. The 20$^{th}$ century brought the development of technology to find the waters' depth in an attempt to identify obstacles before ships encountered them.

For the 21st century, NOAA is implementing its new Electronic Navigational Charts, which can meet demands for greater protection of life, property, and the environment, as well as significantly improve the efficiency of maritime commerce. Using sources ranging from the USCG's weekly Notice to Mariners to letters from companies describing cables laid and channels dredged, NOAA cartographers have equipped each electronic chart with embedded information about hundreds of navigational aids, obstacles, and landmarks. By the end of 2000, NOAA expects to have 90 Electronic Navigational Charts in circulation, focusing on 15 to 20 critical ports on the east and west coasts of the United States [Gugliotta 2000].

**Vessel Traffic Management:** In 1972, Congress passed the Ports and Waterways Safety Act. This act authorizes the USCG to establish, operate, and maintain vessel traffic services for ports, harbors, and other waters subject to congested vessel traffic. The USCG operates the Vessel Traffic Service in nine major U.S. ports and, since 1994, has shared responsibilities with the State of California at the Port of Los Angeles-Long Beach [USDOT BTS, MARAD, and USCG 1999]. In 1975, Vessel Traffic Service was mainly nonelectronic and relied heavily on the skill of the mariner and on vessel construction. Today's radar, closed-circuit television, radiotelephone, or a combination of these devices, provides surveillance of critical areas.

The methods used to gather and distribute vessel traffic and marine safety information need improvement. New approaches are necessary to improve the timeliness of information, increase overall distribution capacity and quality, and conform to the operation of modern navigation systems. Fully automated approaches to information distribution can improve safety, while reducing implementation and operating costs and reducing the communications congestion on the VHF marine frequencies. The methods, technologies, and standards that can support full automation of a modern vessel traffic management information service need to be developed, tested, and demonstrated under a variety of marine conditions. They also need to be evaluated with respect to their sensitivity and responsiveness to the operational needs of the marine community.

As part of the Vessel Traffic Management, an Automated Identification System has been developed. It includes nine shipboard broadcast transponder systems, operating in the VHF maritime band, capable of sending identification, position, heading, ship length, beam, draught, and hazardous cargo information to ships and to shore. The system is designed to reduce the number of vessel incidents in ports and busy waterways by providing ships with up-to-the-minute data on traffic conditions on the water. It also is capable of handling more than 2,000 reports per minute and updates as often as every two seconds [USDOT BTS, MARAD, and USCG 1999].

**Vessel Propulsion:** The 20$^{th}$ century saw the demise of sailing ships, the rise and fall of steamships, and the rise of diesel engines. Scientific advances in hull design, the use of bilge keels, and the adoption of improved ballasting techniques produced more stable vessels. Not only did new hull designs reduce roll, but diesel engines also kept the vessels headed into the wind for even greater stability. However, they were not necessarily environmentally friendly. Research and development regarding vessel propulsion designs were focused on energy efficiency. Today studies are being conducted to develop fuel cell-based propulsion systems. These demonstrate the feasibility of reforming marine diesel to generate electric power using current fuel cell technology. Due to their higher efficiency, fuel cells can generate power using 25-30 percent less fuel than existing marine diesels or gas turbines [USCG 1999]. While it appears technically feasible to implement such technology, the future development of these systems for shipboard use remains an issue.

Initial U.S. Navy and USCG studies showed that existing land-based fuel cell systems need to be made lighter, more compact, and resistant to salt, air and high shock environments before they are suitable for marine use. Fuel cell developers are reluctant to devote resources to meeting these unique shipboard requirements until they are persuaded that a sufficient marine market exists. Federal agencies, such as the U.S. Navy, USCG, and Maritime Administration, are contributing to this effort. Fuel cells are thermally efficient, have low vibration and noise levels, and produce low exhaust emissions.

**Vessel Construction and Cargo Handling:** During the 1970s, intermodal shipping was a new concept. Examples of new generation ships were barge carriers (lighter aboard ship and SEABEE systems), liquid natural gas tankers, and containerships. Fast containerships had capacities of approximately 3,000 20-foot equivalent units (TEUs) and traveled at speeds between 25 and 36 knots.

Today's container vessels have cargo capacity up to about 7,000 TEUs and travel at speeds of 18 to 25 knots [Cargo Systems 1999]. Future container vessel capacity of 13,000 TEUs is being considered. In order to handle the expected increase in container vessels and their cargo capacity, port terminals will need to expand and increase productivity of intermodal services. Sophisticated gate systems are being installed in ports to expedite truck movements into and out of terminals. The maritime industry is increasingly integrating electronic tools, such as the Internet, and e-commerce is developing in the industry to better coordinate cargo bookings and freight management.

Maritime safety continues to be a high priority as high-speed or "fast ferries" (ferries with speeds of at least 25 knots) carry more passengers in the United States every year and as the number of bigger and faster personal watercraft is increasing.

**Positioning:** Highly accurate and affordable GPS make real-time position information available worldwide. Just as early navigators needed charts and astronomical almanacs to derive their position using a sextant and chronometer, GPS and other modern systems operate in concert with high-precision digital charts.

The DGPS was developed by the USCG and provides coastal coverage of the continental United States, the Great Lakes, Puerto Rico, portions of Alaska and Hawaii, and portions of the Mississippi River Basin.

The National Geodetic Survey (NGS), an office of NOAA's National Ocean Service, manages and coordinates a nationwide network of continuously operating reference stations (CORS) that provides GPS carrier phase and code range measurements in support of three-dimensional positioning activities throughout the United States and its territories. Some of these stations also provide meteorological data.

As of 2000, CORS data were available from 191 stations [Weston 2000]. A complete NGS CORS network is not anticipated before 2004, when other CORS-compatible networks such as the USDOT-sponsored NDGPS network become fully operational. The remainder of the stations incorporated into the NGS CORS network will be operated by a large number of different cooperating organizations to support diverse applications. Non-USDOT organizations currently contributing sites to the NGS CORS network include several federal, state, and local agencies, as well as academia and private industry.

## Keys to the Future

Over the next 25 years, innovative technologies and new operational concepts will revolutionize the maritime industry and make it safer and more productive. These include developing and implementing computer-assisted vessel and cargo tracking systems; advanced navigation aids; remote pollution-monitoring; and other ship and landside, including port and intermodal system. Effective use of these technologies will be critical to taking full advantage of the potential of faster ships and more efficient ports now being developed to serve growing global trade. Leveraging emerging technologies will also be critical to ensuring U.S. global competitiveness. Overall, maritime operations will come to resemble a well-coordinated and managed enterprise, akin to aviation, rather than the traditional image of autonomous ships acting independently on the judgment and intuition of only their captains.

These improvements in operational concepts will enable the system to deal with a much broader range of maritime vehicles and services. Ferry service will probably become more prevalent, to compensate for reduced land available in highly developed areas. High-speed hydrofoils, catamarans, SWATH (small water area twin-hull) ships and hovercraft will operate as high-speed ferries in the coastal mega-cities that will have evolved from today's east and west coast urban complexes.

Intelligent vessel traffic services, coupled with differential GPS navigation, electronic charts, and related vessel improvements, will greatly improve the safety and efficiency of the marine transportation system. Marine security information will be readily available to vessel operators, integrated into the displays of data from which control decisions are made. Ocean-going vessels will be responsible for a large proportion of international movement of bulk commodities, but intelligent control technologies, improved weather forecasting, and higher vessel speeds will have increased the safety of these operations while simultaneously improving their productivity. As required by the Oil Pollution Act of 1990, only double-hulled tankers will be in service in U.S. waters.

The growth of global tourism will lead to more cruise ships of all sizes, linked to plains and trains through multimodal port terminals. These vessels will carry international and U.S. vacationers across the oceans and major inland waterways. Some forecast particular growth in very large ocean liners, carrying several thousand passengers. Advanced super-high speed "techno-superliners"—the next generation 50-100 knot passenger ships—will be operating both as long-distance coastal and ocean-crossing carriers. These vessel technologies applied to tomorrow's container ships, tankers, and bulk carriers, will help deal with greatly increased world trade volume by improving the speed of delivery of water cargo. Mega-float offshore airports and intermodal terminal ports will be coupled with high-speed sea ferries to solve the airport capacity constraints and better serve the U.S. and world coastal mega-city hubs. Larger and larger cruise ships may evolve into self-propelled floating resort "cities," which can migrate based on changing weather and climate conditions.

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